



Office of Transport Safety Investigations

BUS SAFETY INVESTIGATION REPORT

BUS WHEEL SEPARATION

MEDOWIE

8 FEBRUARY 2010



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Established on 1 January 2004 by the *Transport Administration Act 1988*, and confirmed by amending legislation as an independent statutory office on 1 July 2005, OTSI is responsible for determining the causes and contributing factors of accidents and to make recommendations for the implementation of remedial safety action to prevent recurrence. Importantly, however, OTSI does not confine itself to the consideration of just those matters that caused or contributed to a particular accident; it also seeks to identify any transport safety matters which, if left unaddressed, might contribute to other accidents.

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Once OTSI has completed an investigation, its report is provided to the NSW Minister for Transport for tabling in Parliament. The Minister is required to table the report in both Houses of the NSW Parliament within seven days of receiving it. Following tabling, the report is published on OTSI's website at www.otsi.nsw.gov.au.

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EXECUTIVE SUMMARY

At approximately 3.15pm on Monday 8 February 2010, a Mercedes Benz 1621 bus owned by Hunter Valley Buses and carrying 79 school students on a regular afternoon school run was travelling in a generally Easterly direction along Richardson Road, between Raymond Terrace and Medowie, when the driver felt the rear of the bus wobble. Moments later, he observed through his mirrors, two rear wheels leave the bus, with one travelling off to the left and the other to the right. The left hand rear corner of the bus dropped to the ground and the driver brought the bus to a stop while keeping the bus wholly within his lane.

Police and bus company representatives attended the incident scene and recovered one of the wheels from the edge of Grahamstown Lake. An Office of Transport Safety Investigations (OTSI) investigator attended the location the next day and commenced an investigation into the circumstances surrounding the incident.

The bus had undergone repairs on 28 November 2009, during which time the rear wheels on both sides were removed and replaced. It was established that the wheels were fitted to the bus without undergoing a final re-tensioning sequence.

Over the subsequent 42 days and 2,540 kilometres travelled, the wheel nuts came loose and detached, with at least eight of the nuts falling into and travelling with the outer wheel after separating from the bus. No absence or loosening of wheel nuts was observed during the driver's pre-departure checks.

The Company has appropriate policies and procedures in place for the task of tensioning fasteners as part of wheel re-fitting following repair or routine servicing work. In the process of closing out the original work order on the computer, the workshop supervisor performs an additional step which generates a work order for a subsequent tension check of the wheel nuts. In this instance the step was omitted and went undetected as there was no backup or verification provided for in the procedure.

A similar incident occurred in May 2009, involving the same parent company. The investigation into that incident found that stricter control of workshop practices was required.

Following the 2009 incident, the parent company introduced a trial of plastic indicator tags fitted to the wheels as a visual aid to show when a wheel nut is loosening. These tags were not fitted to the bus involved in this incident.

In response to recommendations in the Draft Investigation Report, ComfortDelGro Cabcharge Pty. Ltd., the owner of Hunter Valley Buses, reports having:

- implemented an additional step in the work order handling process to visually alert supervisors to the requirement for a wheel nut tension check, and
- initiated the implementation of an extension to their general safety tag system which will alert a driver when a tension check is overdue on their bus.

It is recommended that these initiatives now be fully implemented across all their bus fleets.

By way of alerting the industry to the issues that have arisen in this investigation, it is recommended that the NSW Department of Transport and Infrastructure highlight to bus operators the need for backup checks for safety critical procedures and the efficacy of fitting indicator tags to enhance detection of loose wheel nuts.

The incident occurred on a State managed road with a speed limit of 80 km/h. There are no physical barriers in the general vicinity to prevent a vehicle from leaving the roadway and travelling down into Grahamstown Lake. It is recommended that the Roads and Traffic Authority conduct an analysis of the risks associated with motor vehicles leaving the pavement while travelling along Richardson Road on the perimeter of Grahamstown Lake, with a view to installing some form of crash barrier.

PART 1 CIRCUMSTANCES OF THE INCIDENT

The Incident

- 1.1 At approximately 3.15pm on Monday 8 February 2010, a bus owned by Hunter Valley Buses¹ was carrying 79 school students on a regular afternoon school run when it lost both nearside² rear wheels.
- 1.2 The bus was travelling at approximately 70 km/h along Richardson Road heading from Raymond Terrace to Medowie. The driver reported that he felt a wobble at the rear of the bus before noticing one wheel travel off to the left hand side and one off to the right. Realising that he had lost two rear wheels, he kept the bus on course and avoided using the brakes to slow down, instead, changing down through the gears as the bus slowed to a stop. Marks on the road showed that the bus' undercarriage scraped along the roadway for approximately 134 metres after losing its wheels.
- 1.3 The bus driver ensured that all on board were uninjured and then proceeded to inform his depot of the incident. Police attended and diverted traffic around the stranded bus before it could be recovered and towed back to its depot at Thornton for examination.
- 1.4 Bus company representatives retrieved the inner wheel which had rolled down an embankment and come to rest on the edge of Grahamstown Lake. They searched into the evening for the outer wheel without success. No wheel nuts were located in the vicinity of the separation.
- 1.5 OTSI was notified of the incident and deployed an investigator the next morning. The bus was taken out of service pending examination.

¹ Hunter Valley Buses is a brand owned by ComfortDelGro Cabcharge Pty. Ltd.

² Nearside of a vehicle refers to the side closest to the gutter in the direction of travel. For right hand drive Australian passenger vehicles, the passenger's side of the vehicle is the nearside, whereas the driver's side is the offside.

Location

- 1.6 Richardson Road runs around the south-western perimeter of Grahamstown Lake (see *Figure 1*). It is a two way road signposted at 80 km/h.

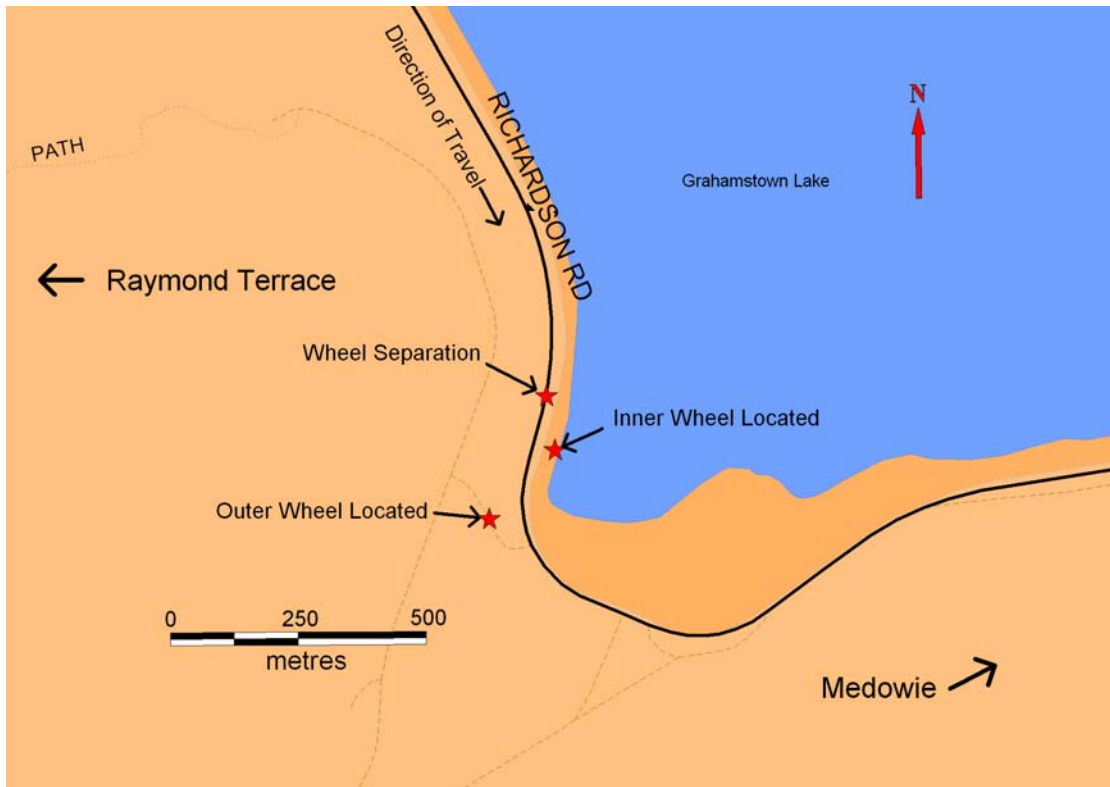


Figure 1: Incident Location

- 1.7 The wheels separated from the bus on a stretch of road marked with double unbroken lane separation lines. To the left in the direction of travel are a grass shoulder and a slight embankment, beyond which the ground slopes down to the edge of the Lake. On the right hand side, the shoulder of the road leads to a significant slope down into a gully.

Investigation Process

- 1.8 The bus was examined at the depot in an effort to determine how the wheels had come off. The evidence available included the bus, with the hub and all its studs attached, and the inner rear wheel which had been recovered after the incident. *Photograph 1* shows the hub involved.



Photograph 1: Nearside Rear Hub

- 1.9 The inner rim showed evidence within the stud holes that most damage occurred to the rim during braking. *Photograph 2* is a close up of the marks left by one of the studs in the inner wheel.



Photograph 2: Damaged Inner Rim Stud Hole

- 1.10 Without the outer rear rim, it would have been impossible to determine how many nuts had been fitted to the wheel leading up to the separation. All studs displayed a generally clean thread surface, damaged only through contact with the loose rims (see *Photograph 3*). There was no evidence to show that nuts had been torn from studs. That being the case, sabotage through intentional removal or loosening of the wheel nuts could not be ruled out.



Photograph 3: Example of Stud Damage

- 1.11 The Company reported that it had been the victim of a possible sabotage attack on 27 January 2010, when it was found that a bus which had suffered a loss of power had abnormal contaminants in the fuel system.
- 1.12 The driver said that he had checked the wheels before taking the bus into service, noting that all wheel nuts were fitted to the subject wheels. The bus had been parked in the far corner of the yard over night. The area around where the bus had been parked was examined and no evidence was found to suggest that the yard had been broken into. It was also considered unlikely that the wheel nuts were loosened in the yard, as a substantial bar and socket

would have been required to do it. CCTV footage covering the yard was reviewed and nothing suspicious was observed.

- 1.13 Finding the outer rear wheel became crucial, as it would at least confirm the number of wheel nuts fitted because there would be evidence of the nuts fretting against the rim as they worked loose.
- 1.14 The route taken by the bus was retraced in an effort to locate any of the wheel nuts. No wheel nuts were located along the route or at the point where the wheels came off.
- 1.15 After a short search, the outer rear wheel was located lying under a tree (see *Photograph 4*) near the top of an embankment approximately 250 metres from where it came off the bus. The initial search had concentrated on an area closer to where the separation had occurred and it was only by chance that the wheel was spotted on the way to the search location.



Photograph 4: Outer Rear Wheel as Located

- 1.16 The wheel was found lying at the base of a tree with its outside facing up. Initially it appeared that it must have been placed there by somebody, possibly in an effort to secrete it for later retrieval. There were no obvious tracks leading to its resting place and, complicating the find even more, was

that fact that lying right next to the wheel was one of the wheel nuts (see *Photograph 5*). To have ended up where it was, the wheel had to have travelled from the bus, across the oncoming traffic lane, down the side of a slope, through a gully, up an embankment and rolled around the back of a tree.



Photograph 5: Wheel Nut Located Beside Wheel

- 1.17 Vague impressions in the grass showed that a possible path of travel was to the top of the embankment, before hitting a post and wire fence and rolling back down to beneath the tree.
- 1.18 Investigators found a total of eight wheel nuts located within approximately two metres of where the wheel had come to rest. The two remaining nuts were not found and other search methods, such as using a metal detector, were not employed as the rim showed clear signs that ten nuts had been fitted to it (see *Photographs 6 and 7*). All stud holes showed bare metal and fretting where the nut flanges meet the rim.



Photograph 6: All Ten Nuts Marked Rim



Photograph 7: Close View of Fretting Caused by Loose Nuts

- 1.19 Locating eight of the wheel nuts within close proximity to the outer rear wheel indicated they had all fallen off, rather than being ripped from the studs. This would indicate that all eight nuts must have come undone at approximately the same rate. Had that not been the case, some nuts would most likely have been torn from the studs during cornering, when the lateral loading on the rims was the highest.
- 1.20 The driver completed a pre-departure check of the bus as required during which he observed all wheel nuts fitted to the bus. Therefore, the nuts must have come undone over the short journey of approximately 25 kilometres.

Driver's Actions

- 1.21 The driver did not experience any vibrations during the journey until he felt the rear of the bus wobble moments before seeing both rear wheels leave the bus. His reaction was to bring the bus to a stop by going down through the gears as opposed to applying the brakes.
- 1.22 With both nearside rear wheels off the bus, the rear corner dropped to the road and the bus scraped along on its undercarriage, with the hub assembly just clear of the road surface. The brakes would still have functioned as the drum remained fitted to the hub on the nearside. However, it would be expected that braking would be uneven and may have even had the effect of pulling the bus to the right, as only the two front wheels and offside rear wheels would have been providing braking resistance.
- 1.23 The driver's actions in not using the brakes contributed to a controlled stop, with the scrape marks in the road depicting a course which confirmed the bus did not cross to the other side of the road (see *Photograph 8*).
- 1.24 Because of the type of differential fitted to the bus, going down through the gears would have had little effect on arresting the bus' movement, as without the nearside hub being engaged with the roadway in any form, it would have spun freely instead of slowing the bus through the resistance of the engine. However, the driver exercised good control of the bus through maintaining steering and avoiding the use of the service brakes.



Photograph 8: Scrape and Tyre Marks on Road

Coming Loose

- 1.25 Wheel nuts remain tight due to the friction between the mating surfaces of the nut and rim, caused by the tension applied to the stud. Like any threaded fastener, the tighter a nut is turned the more tension is placed on the stud. The studs act as springs to provide the clamping force between the nuts, rims and hub. There is a range within the metallurgical properties of the studs known as the elastic range, where the designated torque applied to the nuts is meant to achieve sufficient clamping force to maintain the integrity of the components. If too little torque is applied to the nuts, there may not be enough clamping force to prevent shock loads from loosening the nuts. Conversely, if there is too much torque applied to the nuts, it is possible to stretch the studs beyond their elastic range and into the plastic range of the metal, effectively allowing any further shock loads to stretch the stud and result in a loss of clamping force.
- 1.26 A loss of clamping force can occur when the surfaces being clamped together are compressible in any way. For example, paint or rust build-up can give rise to a loss of clamping force as the thickness of the build-up is reduced through pressure and friction over time.

- 1.27 Any movement between the bolted components will eventually lead to a loss of clamping force, as the movement will turn the nuts in the direction of least resistance, effectively undoing them.
- 1.28 Once clamping force is lost, vibration causes the nuts to unwind to the point where they will fall off the studs. The factors which determine how long it takes for nuts to fall off once loosened are:
- the level of vibration,
 - the time exposed to vibration, and
 - the friction between the threads of the nut and stud.
- 1.29 The vibration acting on the nuts comes from a variety of sources, including road surface and the movement of mechanical components. While the nuts are tight against the rim, the vibration does not have any effect on moving the nuts as the clamping force produced by the stud prevents any movement.
- 1.30 How long it takes for the nuts to undo is further dependent on the friction between the threaded surfaces of the nuts and studs. The subject nuts and studs were all in good condition, providing little resistance against undoing.
- 1.31 The profile of the rim provided a recess for the nuts to sit in, with centrifugal force holding the nuts in place from when it detached until the wheel lost rotational speed and tipped over.

Data

- 1.32 There is very little data available on wheel separation incidents both nationally and globally. There have been 10 instances of wheel nuts coming loose or wheels separating from buses reported to OTSI since it commenced operations in January 2004. Unlike motor vehicle collisions, wheel separations not involving damage to property or injury to persons are likely to go unreported.

The Bus

- 1.33 The bus is a single door Mercedes Benz 1621 fitted with a manual transmission. It is configured to carry 80 seated passengers and is primarily

used for school runs. The bus was approximately 10 years old at the time of the incident.

- 1.34 Inspection of the bus found no indications that its design contributed to the loosening of the wheel nuts. Having a manual transmission meant that a harsh driving style may place higher shock loads on the studs than an automatic transmission. However, it is unlikely that this contributed to the wheel loss as the driver was a heavy vehicle driver prior to taking up the bus driving role with Hunter Valley Buses.

Maintenance

- 1.35 The most recent documented inspection of the bus was a NSW Roads and Traffic Authority (RTA) safety inspection carried out on 2 February 2010. The inspection was in accordance with the RTA Heavy Vehicle Inspection Scheme (HVIS) which requires heavy vehicles to be examined for roadworthiness every six months. During the inspection, the brakes, suspension and steering of the bus were examined for excess wear or defects. As part of that process, the bus is put on a “shaker”, a device which moves the undercarriage of the bus backwards and forwards to simulate road conditions and identify any loose components. If the wheel nuts had been loose at that time, it would be expected that rim movement would have been detected.
- 1.36 The last record of the rear wheels being removed and replaced was on 28 November 2009. On that day, the bus was recorded as having undergone a full brake re-line. This process required the removal and replacement of all the wheels. Part of the procedure in doing so would have been to tighten the wheel nuts with a tension wrench to a setting in accordance with manufacturers’ specifications.
- 1.37 Based on odometer reading records, the wheels detached 2,546 kilometres after they were removed and replaced for the brake re-line and 632 kilometres after the RTA HVIS examination.

Procedures

- 1.38 ComfortDelgroCabcharge has a specific workshop procedure in place which defines how wheel nuts are tightened. Not only are the wheel nuts to be tensioned using a calibrated tension wrench, but a follow up tension check is to be conducted after 24 hours or 500 km.
- 1.39 The buses are brought into the workshop for repairs as part of a work order system. The work orders are generated through servicing schedules or driver reported defects. The system is computer based, and relies on three stages for the fulfilment of work orders:
- the supervisor provides the mechanics with a work order, outlining what needs to be done,
 - mechanics effect repairs or complete services to the buses and sign off the work order, and
 - the supervisor completes the work order by closing out the job on the computer system.
- 1.40 At the final stage, in the case of wheel removal and replacement being carried out, the supervisor is required to book the bus in with a new work order for the wheel nut tension check. This process involves simply dragging an item from one section of a computer screen to another. Following the wheel work on 28 November 2009, the supervisor did not perform the necessary action to initiate the work order for the tension check through the computer maintenance system. Thus, in the absence of any backup or verification provided for in the procedure, the requirement was not captured and so went unfulfilled.

Bossley Park Incident

- 1.41 On 11 December 2009, OTSI published a report into a similar type of incident involving a bus owned by Westbus.³ The incident occurred on 12 May 2009 when a bus lost an outer rear wheel as it approached an intersection in the suburb of Bonnyrigg. Only one of the 10 wheel nuts was found, not far from where the wheel had separated. Examination of the wheel showed that all 10

³ Westbus is also a brand owned by ComfortDelGro Cabcharge Pty. Ltd. The Report is available on OTSI's website and is entitled: *Bus Rear Wheel Detached and Collided with Oncoming Vehicle, Bossley Park, 12 May 2009.*

wheel nuts had worked loose possibly over a period of days leading up to the separation and following wheel removal and replacement in relation to suspension work. The investigation found that appropriate re-tensioning procedures were in place but were not followed correctly in that the bus had left the depot following repairs 11 days prior and had not been booked in for a mandatory re-tensioning of the wheel nuts. It was recommended that the organisation implement tighter control over workshop procedures.

Tagging Systems

- 1.42 Since the Bossley Park incident, ComfortDelGro Cabcharge has implemented a trial of fitting plastic indicator tags to wheel nuts. The purpose of the tags is to provide a visual aid to determining if wheel nuts are coming loose. The tags are plastic arrows which fit over the wheel nuts and usually are fitted to pairs of nuts with the indicators facing each other (see *Figure 2*). In the event of nuts working loose, the indicator arrows will turn anti-clockwise, disrupting the pattern of original alignment (see *Figure 3*).

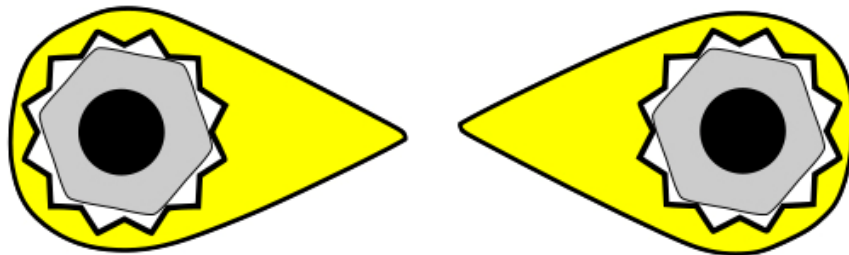


Figure 2: Illustration of Wheel Nut Tags

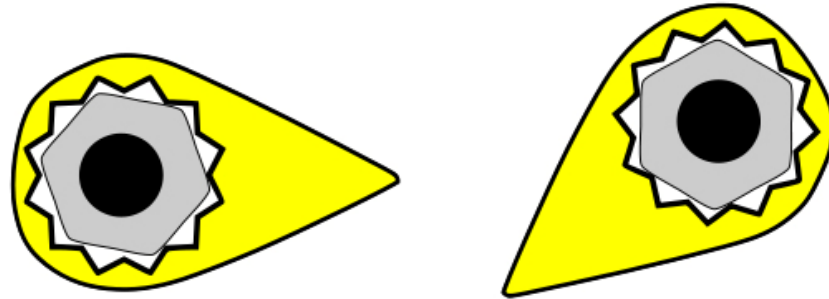


Figure 3: Misaligned Tags Showing Loose Nut

- 1.43 Another bus company has implemented an alternative to this type of indicator tag, whereby two pairs of wheel nuts are fitted with a plastic tag which effectively ties the nuts together (see *Figure 4*).



Figure 4: Alternative System

- 1.44 Both tagging systems introduce an added burden for workshop staff in that tags have to be removed and replaced every time a socket is used on a nut. Furthermore, if the arrow style tags appeared aligned, the mechanic may feel no need to physically check the wheel nut tension.
- 1.45 The tags which prevent nuts from undoing (*Figure 4*) may introduce the added risk that, although the nuts do not appear to have moved, they may in fact be loose due to settling of the clamped surfaces which can occur when rust or paint layers on the rim surface are worn down. If that were the case, the stud assemblies would eventually fail as the rim moved around during travel.

- 1.46 Nevertheless, the tagging systems described above do represent credible methodologies to address the problem of undetected wheel nut loosening.

Adding Defences

- 1.47 By relying on the computerised maintenance system alone, there was no way of physically identifying that the bus required a tension check of the wheel nuts. This allowed the bus to be brought into service without anyone, the driver in particular, being aware that a tension check was required.
- 1.48 If the mechanics involved in removal and replacement of the wheels had marked the bus in some manner, making the outstanding work requirement obvious to the driver, the omission of entering the bus into the computer system could have been detected.
- 1.49 Such marking could involve anything from a label complete with written details, a sticker, or simply just a coloured cable tie around the spoke of the steering wheel. Having the bus identified in that way would alert a driver to the fact of outstanding work needing to be done. In the absence of further explanatory information, such as a work order number or call in 'due by' date, a driver may be required to contact the depot for further instructions. Such a system of physically identifying buses requiring safety critical work would add to what is already a sound procedure, albeit open to human error at just one layer.

Other Observations

Torque settings

- 1.50 In addition to ensuring tension checks are carried out, it is important that the correct tensions are applied to all wheel nuts. Currently, the mechanics are required to carry and refer to a chart to determine the appropriate torque settings for each model of bus. An alternate method of identifying individual bus wheel nut torques through stencilling of the torque figure above the wheel arch was raised with the Company. However, a risk assessment of this strategy resulted in a recommendation against its implementation for a number of reasons including concern that a torque figure could be inadvertently interpreted as a tyre pressure.

Roadside protection

1.51 There are no roadside crash barriers on Richardson Road. Had the driver lost control of the bus and travelled off either side of the road, the outcome may have been tragic. To the left, the bus would have travelled into Grahamstown Lake. Off to the right, the slope of the embankment could easily have caused a rollover (see *Photographs 9 and 10*). The presence of physical barriers for this section of Richardson Road would eliminate this potential risk.



Photograph 9: Richardson Road in the Direction of Travel



Photograph 10: Road Conditions at Point of Separation

Remedial Actions

- 1.52 Since the incident occurred, ComfortDelGro Cabcharge has implemented an additional step in the work order handling process, wherein “Wheels Removed” is stamped on a work order when a wheel is removed for any reason. This aims to reduce the likelihood of supervisors failing to identify a wheel nut tension check requirement and not booking it.
- 1.53 The Company is also in the process of implementing an extension to its general safety tag system which will alert a driver not to drive a bus if the tag remains in the bus at a certain time and date.

PART 2 FINDINGS

Causation

- 2.1 The investigation found that all ten wheel nuts had come loose during the trip between Raymond Terrace and Medowie, with at least eight of the nuts falling off and travelling with the outer wheel after it separated from the bus. Contrary to workshop procedural requirements, the nuts were not subjected to a tension check subsequent to the removal and replacement of wheels as part of a full brake re-line completed on 28 November 2009.

Contributory Factors

- 2.2 Tension checks are arranged by the workshop supervisor through the production of a computer generated work order at the stage of closing out repair or servicing work involving wheel removal. In this instance the initiating action was not undertaken and so a work order was not generated thus allowing the bus to continue in operation without the full procedure having been completed.
- 2.3 The current workshop procedure does not provide any backup checks or alerts in the event of the tension check work order not being generated. Therefore, instituting a second line of defence would be appropriate. This could take the form of a visual indicator to alert drivers there is outstanding work to be completed on their bus and prompting communication between them and the workshop.
- 2.4 Since a similar incident of a wheel separating from a bus in May 2009, there have been trials of fitting plastic indicator tags to wheel nuts to provide a visual aid to determining if wheel nuts are coming loose. They were not fitted to the bus which is the subject of this investigation. Regardless of such strategies, it is considered essential that tension checks after wheel replacement continue to be completed in accordance with current procedures.

- 2.5 The driver's actions in not using the brakes contributed to a controlled stop of the bus and assisted in preventing the bus from crossing into the oncoming lane.

Other Observations

- 2.6 In the vicinity of the incident location, the road formation slopes away on both sides without there being any barriers against the danger to vehicles if they veered off the road.

Remedial Actions

- 2.7 ComfortDelGro Cabcharge reports having implemented an additional step in the work order handling process to alert supervisors when a wheel nut tension check is required, and being in the process of implementing an extension to their general safety tag system which will alert a driver when a wheel nut tension check is overdue on their bus.

PART 3 RECOMMENDATIONS

- 3.1 In order to prevent a recurrence of this type of incident, the following remedial safety actions are recommended for implementation by the specified responsible entities.

ComfortDelGro Cabcharge Pty. Ltd.

- 3.2 Maintain the current procedure for producing work orders for tension checks of wheel nuts following removal and replacement of wheels and fully implement, across all its bus fleets, its initiatives to alert workshop supervisors and drivers by way of visual prompts when such work remains outstanding.

NSW Department of Transport and Infrastructure

- 3.3 Issue a safety, information or equivalent alert to bus operators highlighting the need for backup checks for safety critical procedures, using this investigation as a case study.
- 3.4 Issue a safety, information or equivalent notice to bus operators concerning the efficacy of fitting indicator tags to enhance detection of loose wheel nuts.

NSW Roads and Traffic Authority

- 3.5 Conduct an analysis of the risks associated with motor vehicles leaving the pavement while travelling along Richardson Road on the perimeter of Grahamstown Lake with a view to installing some form of crash barrier.

PART 4 APPENDIX

Appendix 1: Sources and Submissions

Sources of Information

- ComfortDelGro Cabcharge (Hunter Valley Buses)
- Thornton Depot staff

Submissions

The Chief investigator forwarded a copy of the Draft Report to the Directly Involved Parties (DIPs) to provide them with the opportunity to contribute to the compilation of the Final Report by verifying the factual information, scrutinising the analysis, findings and recommendations, and to submit recommendations for amendments to the Draft Report that they believed would enhance the accuracy, logic, integrity and resilience of the Investigation Report. The following DIPs were invited to make submissions on the Draft Report:

- ComfortDelGro Cabcharge
- Independent Transport Safety and Reliability Regulator (ITSRR)
- NSW Transport and Infrastructure (NSWTI)
- NSW Roads and Traffic Authority

Submissions were received from all parties and the Chief Investigator considered all representations made by DIPs and responded to the author of each of the submissions advising which of their recommended amendments would be incorporated in the Final Report, and those that would not. Where any recommended amendment was excluded, the reasons for doing so were explained.