BUS SAFETY INVESTIGATION REPORT

BUS REAR WHEEL DETACHED AND COLLIDED WITH ONCOMING VEHICLE

BOSSLEY PARK

12 MAY 2009
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Released under the provisions of Section 45C(2) of the Transport Administration Act 1988 and Section 46BA(2) of the Passenger Transport Act 1990

Investigation Reference 04440
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TABLE OF CONTENTS

TABLE OF FIGURES
TABLE OF PHOTOS
EXECUTIVE SUMMARY
PART 1 FACTUAL INFORMATION
   Accident Narrative
   Location
   Incident Response
   Damage
PART 2 ANALYSIS
   Wheel Separation
   Wheel Configuration
   Wheel Attachment
   Mechanism of Detachment
   Fitment Practice
   Depot Variations
   Manufacturer’s Recommendations
   Observations
   Inspection Procedures
   Industry Practice
   Maintaining Integrity
   Remedial Actions
   Frequency of Incident Type
PART 3 FINDINGS
   Causation
   Contributing Factors
   Other Safety Matters
PART 4 RECOMMENDATIONS
   ComfortDelGro Cabcharge Pty. Ltd.
   NSW Department of Transport and Infrastructure
APPENDIX 1 SOURCES AND SUBMISSIONS
### TABLE OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1:</td>
<td>Incident Location</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2:</td>
<td>Cross section of rear hub assembly</td>
<td>6</td>
</tr>
<tr>
<td>Figure 3:</td>
<td>Illustration of tags fitted showing no movement, then showing one nut out of alignment</td>
<td>21</td>
</tr>
</tbody>
</table>

### TABLE OF PHOTOS

<table>
<thead>
<tr>
<th>Photo</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo 1:</td>
<td>Damage to Hyundai sedan</td>
<td>2</td>
</tr>
<tr>
<td>Photo 2:</td>
<td>Damage to wheel rim</td>
<td>3</td>
</tr>
<tr>
<td>Photo 3:</td>
<td>Passenger’s side rear hub assembly</td>
<td>5</td>
</tr>
<tr>
<td>Photo 4:</td>
<td>Wear on outer rim and build up of paint</td>
<td>8</td>
</tr>
<tr>
<td>Photo 5:</td>
<td>Wheel stud with damaged thread</td>
<td>9</td>
</tr>
<tr>
<td>Photo 6:</td>
<td>Corresponding thread from wheel nut found close to incident scene</td>
<td>9</td>
</tr>
<tr>
<td>Photo 7:</td>
<td>Wheel stud without nut during wheel separation</td>
<td>10</td>
</tr>
<tr>
<td>Photo 8:</td>
<td>Damage to shoulder of hub which pilots the rim</td>
<td>10</td>
</tr>
<tr>
<td>Photo 9:</td>
<td>Impact gun used to initially tighten wheel nuts</td>
<td>11</td>
</tr>
<tr>
<td>Photo 10:</td>
<td>Torque wrench used for final tensioning of wheel nuts</td>
<td>12</td>
</tr>
<tr>
<td>Photo 11:</td>
<td>Wheel nut without lubrication</td>
<td>14</td>
</tr>
<tr>
<td>Photo 12:</td>
<td>View of passenger’s side rear wheel, taken 1 m diagonally to the front</td>
<td>16</td>
</tr>
<tr>
<td>Photo 13:</td>
<td>View of same wheel taken from a kneeling position beside the bus.</td>
<td>16</td>
</tr>
<tr>
<td>Photo 14:</td>
<td>No evidence of lubrication inside wheel nut located after incident</td>
<td>19</td>
</tr>
<tr>
<td>Photo 15:</td>
<td>Inside of outer rim showing elongated holes and at least two layers of paint once present</td>
<td>20</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

At approximately 2.10pm on Tuesday, 12 May 2009, a Hyundai sedan waiting to turn left onto Cowpasture Road from Prairie Vale Road at Bossley Park was hit by a wheel which had come adrift from a Westbus Volvo bus at the opposite side of the intersection. The female driver of the car did not require any medical attention but the car sustained moderate front end damage.

Police and bus company representatives attended the incident scene and one of the 10 wheel nuts used to fasten the wheels to the bus was located not far from where the wheel had separated from the bus. An OTSI investigator attended the location the next day and commenced an investigation into the circumstances surrounding the incident.

The bus had undergone repairs on 4 May 2009, during which time the rear wheels on both sides were removed and replaced. It was established that the passenger’s side rear wheels were fitted to the bus without undergoing a final tensioning sequence.

Over the subsequent eight days and 1,504km travelled, the wheel nuts came loose and detached with the final nut being torn from the stud just prior to the wheel separating from the bus. Despite a requirement for drivers to conduct pre-departure checks, the loosening and loss of the wheel nuts went unnoticed.

The Operator has appropriate policies and procedures in place for the task of tensioning fasteners as part of wheel re-fitting. They were not followed on this occasion due a miscommunication among depot workshop staff. If they had been followed, the incident would not have occurred.

An examination of a sample of bus wheel fitting practices revealed a variety of techniques are being employed. The more robust practices use a torque wrench in addition to an impact gun followed up with a wheel nut tension check after a road test.
During the process of examining practices it was found that a build up of contamination of rim surfaces and lack of lubrication of wheel fasteners was not uncommon. Painted, rusted or otherwise contaminated rim surfaces can lead to fasteners loosening as the materials compress and disperse over time. Lubrication of clean thread surfaces reduces the friction between the stud and the nut, providing greater clamping force when tensioned due to less friction.

In addition to emphasising the need for adherence to and supervision of policies and procedures, the investigation recommends the operator review the adequacy of existing policies and procedures with regard to their reference to manufacturers’ recommendations, contamination of rim surfaces and lubrication of wheel fasteners.

It is also recommended that the NSW Department of Transport and Infrastructure, through the Bus Operator Accreditation System (BOAS) auditing process, ensure that accredited operators have in place and adhere to adequate, specific procedures for ensuring the correct tension is established and maintained on bus wheel fasteners.
PART 1  FACTUAL INFORMATION

Accident Narrative

1.1 About 2.10pm on Tuesday, 12 May 2009, a Volvo bus operated by Westbus’ Bonnyrigg Depot\(^1\) was travelling East on Stockdale Crescent at Bossley Park, approaching the intersection with Cowpasture Road. On the opposite side of the intersection, a Hyundai motor vehicle was stationary in Prairie Vale Road, waiting to turn left onto Cowpasture Road. As the bus driver slowed for the red light facing him, the passenger side rear outer wheel detached and rolled past the bus and across the intersection, colliding with the front of the stationary car before rolling off to the side of the road.

1.2 The car sustained moderate damage and was able to be driven from the scene. When spoken to regarding the incident, the driver of the car claimed that the incident exacerbated an existing injury which was the subject of a worker’s compensation claim. Given that no medical assistance was required at the time of the incident, OTSI was unable to determine if the wheel hitting the car had caused the driver any injuries.

Location

1.3 Stockdale Crescent is a residential two way street with a posted speed limit of 60 km/h. Approaching Cowpasture Road in an Easterly direction, there is a moderate downhill gradient and a left hand bend before the road becomes two marked lanes from approximately 50m prior to the intersection (see Figure 1).

1.4 The opposite side of the intersection is the Western end of Prairie Vale Road, a two way road with two lanes in each direction. The driver of the car was in the left hand lane, waiting to turn left onto Cowpasture Road.

1.5 Because Cowpasture Road is the border between Bossley Park and Abbotsbury, the actual wheel separation from the bus occurred in Abbotsbury and the collision with the car in Bossley Park.

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\(^1\) Westbus is a wholly owned subsidiary of ComfortDelGro Cabcharge Pty Ltd.
Incident Response

1.6  Representatives from Westbus attended the scene, along with general duties Police from Fairfield. Medical assistance was not required and the Police involvement was limited to defecting the bus.

Damage

1.7  The Hyundai sedan which was hit by the wheel sustained moderate front end damage (see Photo 1). The repair bill which was covered by the bus company was in the vicinity of $3,500.

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Photo 1: Damage to Hyundai sedan

1.8  The damage to the bus was confined to the rear hub, studs and rims, which were damaged beyond repair. Photo 2 shows the damage to the stud holes of the rear rim.
Photo 2: Damage to wheel rim
PART 2 ANALYSIS

Wheel Separation

2.1 Based on the bus driver’s account that the separated wheel passed his bus on approach to the intersection, a straight line of trajectory between the estimated point of impact with the car and the point where the wheel detached from the hub was drawn using a plan view of the location. The distance of travel of the wheel is estimated at 145m. Figure 1 illustrates the line of trajectory.

![Figure 1: Incident Location]

2.2 The moderate bend before the point where the wheel separated would not have excluded the bus from travelling close to the posted speed limit of 60 km/h. Given a slight downhill grade before the intersection, the momentum of the wheel is likely to have maintained a speed close to that at the point of separation, potentially hitting the car at up to 60km/h.
Wheel Configuration

2.3 The rear axle of the bus was fitted with dual wheels, typical of heavy vehicle applications. Each rim and tyre combination weighs approximately 90kg. They are one piece steel rims fitted with 275/70R 22.5 road tyres.

2.4 The wheel rims are bolted to the hub through a series of 10 studs (see Photo 3). Aside from securing the wheel to the hub, the studs are responsible for transmitting braking and acceleration torque through the wheels (see Figure 2). On hub piloted rims, the wheel is centralised by the fit of the rim centre over the hub diameter, with the drive and braking torque carried through the studs.

Photo 3: Passenger’s side rear hub assembly
Wheel Attachment

2.5 Wheels are removed and replaced for tyre changes and other maintenance and servicing requirements. The secure fitment of the wheel relies on one factor, i.e., the correct clamping force between the nut and hub gained through appropriate tensioning of the wheel nuts.

2.6 Once tensioned correctly, there should be enough clamping force to maintain integrity of the wheel to hub assembly until later removal is required.

2.7 There are three key requirements in obtaining and maintaining adequate clamping force:

a. the torque applied to the nut meets the required specification;

b. the stud is of the required tensile strength to maintain tension without stretching, and

c. the surfaces being clamped together are incompressible.
2.8 In effect, the stud acts as a spring holding the rims between the nut and surface of the hub. If the nut is tensioned insufficiently for the tension of the stud to maintain clamping force, the cyclic forces acting on the stud will lead to the stud failing under shear forces, or through complications arising from the wheel nuts loosening. Conversely, excessive tension placed on the stud through over tightening of the nut will stretch the stud beyond its elastic range and into its plastic range, no longer providing continuous clamping force.

2.9 Correct tensioning can only be accomplished when the threads of both the wheel nut and stud are in good condition and free of excessive friction. The threaded surfaces, and in some applications the interface between the nut and rim, require lubrication. The purpose of the lubrication of the nut and stud is to reduce the friction between the nut, stud and rim so that a torque can be more directly translated to clamping force. Excessive friction due to damaged or poorly lubricated threads will result in an under-tensioned stud, as most of the tensioning torque is consumed through friction.

2.10 Studs which are continually over or under tensioned have a reduced service life due to the additional stresses encountered from the rim moving around the stud under load.

**Mechanism of Detachment**

2.11 One wheel nut from the bus was located by police approximately 100m before the point where the wheel separated. OTSI re-traced the entire route taken by the bus on the day of the incident but none of the remaining nine wheel nuts were located. The absence of these nuts indicated that it was highly likely that the wheel nuts had loosened and dropped off the bus on the days before the incident.

2.12 The last recorded removal and replacement of the passenger’s side rear wheels took place on 4 May 2009 when workshop staff replaced worn suspension bushes at the rear of the bus. There was no further maintenance carried out on the bus over the subsequent eight days leading up to the incident. The outer face of the outer rim showed clear evidence of fretting between the nut flange and the rim at all wheel nut locations (see Photo 4).
This provided an indication that the bus had left the workshop with all nuts fitted.

![Photo 4: Wear on outer rim and build up of paint](image)

2.13 An examination of the studs revealed that one nut had torn from the stud with approximately 15mm of thread still engaged. This indicated that it was the last nut retaining the wheel before separation. The thread damage on the stud also aligned with the thread damage on the nut found close to the incident site (see Photos 5 and 6). The remaining nine studs showed signs of the nuts being absent as the wheel finally separated, with impact damage to the outside edge of the studs (see Photo 7), caused by the rim’s stud hole dragging over the stud on separation.
Photo 5: Wheel stud with damaged thread

Photo 6: Corresponding thread from wheel nut found close to incident scene
2.14 The shoulder of the hub which pilots both rims was worn where the outer rim was moving around while not secured tightly (see Photo 8).
2.15 The bus had travelled 1,504km since the wheels had been fitted on 4 May 2009. This would have been ample time for the nuts to work loose had they not have been tensioned to the correct settings.

### Fitment Practice

2.16 The practice in place at the Bonnyrigg Depot workshop for wheel fitment at the time of the incident was to fasten the wheel to the hub initially using an impact gun (also known as a rattle gun (*Photo 9*)) which is a pneumatic hand tool with a hexagonal socket connected to its square drive. It tightens fasteners through a combination of torque and impact forces. Once done up with the impact gun, the nuts are further tensioned through the use of a torque wrench (*Photo 10*). A torque wrench is a calibrated socket wrench which can be set to a range of settings which, on reaching the required torque setting, breaks away at a pivot point to indicate that the correct tension has been reached.

*Photo 9: Impact gun used to initially tighten wheel nuts*
2.17 On 4 May 2009, a work order was completed for the fitment of the suspension work and, in accordance with standard practice, signed off by both the two mechanics involved and the workshop supervisor. There was no discreet reference to wheel removal and replacement as it is a given that this is required to carry out the suspension work.

2.18 Once the bus had left the workshop, contrary to policy, there was no work order generated for the re-tensioning of the rear wheels. Therefore, this would not have been done again until the next routine service or maintenance requirement.

2.19 An operator’s investigation into the incident was undertaken by the Depot Manager. The versions of events given by the workshop staff provided evidence of a communication breakdown during the handover between the mechanics from the day shift to the afternoon shift supervisor. This resulted in the bus leaving the workshop with only the driver’s side rear wheels tensioned correctly. It was apparent from statements provided by the two mechanics
that the passenger’s side wheel nuts were run up only with an impact gun and were to be tensioned later.

2.20 If the work order had remained open for a re-tension, the inadequately tensioned passenger’s side rear wheel would have been detected and rectified, thereby preventing the wheel separation.

Depot Variations

2.21 A sample of five bus depot workshops was selected at random for the purpose of gaining a wider knowledge of industry practice. Three different bus companies were represented including Westbus, and two workshops were at alternative Westbus depots. Common to all workshops was the use of an impact gun for running the nuts down the thread, followed by manual tensioning. Some of the depots utilised external contractors for all wheel and tyre work, whereas other depots changed their own wheels, but left tyre changing only to outside contractors.

2.22 Of the five depots inspected, one did not use a torque wrench for final tensioning, instead using custom made bars which comprised of a socket welded to a length of steel bar. The depots which did utilise a torque wrench all had tooling with a current calibration certificate.

2.23 Westbus has a computerised maintenance system in place wherein, once a wheel had been fitted to a bus, the work order is left open until the tension of the wheel nuts is confirmed through a second check the following day. Due to a communication breakdown between workshop mechanics and the supervisor, that procedure was not followed at the Bonnyrigg Depot for the bus involved in this incident. The workshops at depots of companies other than Westbus relied on the short time intervals between services for checking the wheel nut tension.

2.24 The depots which used torque wrenches used a pre-set tension of between 600Nm and 700Nm, depending on the torque specified by the manufacturer of the bus chassis. This torque range is consistent with a general torque specification for M22 fasteners as used on buses.
Manufacturer's Recommendations

2.25 Volvo recommends that wheel nuts be tightened using a torque turn method, wherein the nuts are tightened in sequence to 200Nm before turning the nut through 90° to obtain final tension. This procedure is followed up with a tension check after approximately 200km of travel, when each wheel nut should be checked to ensure that its tension is at least 670Nm. If a nut is found to turn at 670Nm, the tensioning process is to be repeated.

Observations

2.26 At one of the Westbus depots, when wheel nuts were removed from a bus to allow OTSI to capture a number of photographic images, it was found that all nuts and studs on the bus involved were devoid of lubrication (see Photo 11). When the second and third year apprentices assisting OTSI were questioned on the application of lubricant to wheel fasteners, a mixed response indicated that they were of the belief that either no lubricant at all should be used or, if used, only on certain fastener types.

Photo 11: Wheel nut without lubrication
Apprentices entering the bus repair industry in NSW usually complete a trade course in heavy vehicle road transport through TAFE NSW. To ascertain what was being taught to apprentices in relation to wheel nut and stud lubrication, the head teacher of heavy vehicle mechanics at Wetherill Park TAFE\(^2\) was contacted. The head teacher confirmed in writing that all apprentices are taught from the same text, further confirming that the text makes particular reference to the need to lubricate thread surfaces on the fasteners of hub piloted rims.

As a result of OTSI alerting TAFE to the possible ambiguity surrounding lubrication of wheel nuts, a notice was distributed by the head teacher to all teaching staff, outlining the need to emphasise that lubrication should be used on hub piloted rims and that the contents of the common text must be used.

**Inspection Procedures**

Westbus drivers carry out a physical pre-departure inspection of their bus daily, but this is limited to a walk around the bus exterior and not a check of individual components. In order to establish what the drivers may have seen in the days leading up to the incident, seven wheel nuts were removed from the studs of a like bus’ rear wheel. The remaining three nuts were loosened.

Photo 12 shows the rear wheel of the bus when viewed from approximately one metre to the front and one metre away from the side of the bus, from an eye level of approximately 165cm. Due to the offset of the outer rear rim, none of the wheel nuts can be seen. Only the nuts around the axle flange are visible. Photo 13 is a side on view taken from a kneeling position which, aside from moving approximately 2.5m away from the bus, was the only position from which all 10 wheel nuts could be seen.

\(^2\) Wetherill Park TAFE is the main centre offering this training in the Sydney area.
Photo 12: View of passenger’s side rear wheel, taken 1 m diagonally to the front

Photo 13: View of same wheel taken from a kneeling position beside the bus.
From *Photo 12*, it would appear unlikely that anyone walking past the bus and glancing down at the wheels would gain a clear impression of the condition of a wheel’s fasteners. In a depot parking situation, the buses are normally parked less than 2.5m apart, therefore making sighting the wheel nuts only possible through kneeling or bending. Indeed, from *Photo 13*, wheel fastener anomalies may even then not be entirely obvious at a glance.

It would be highly likely that a driver would detect the presence of a loose front wheel due to steering vibration and knocking below the driver generated by a loose wheel on the steer axle. In view of the absence of any reports by passengers alerting the driver to abnormalities at the rear of the bus, it is assumed that the loose rear wheel went undetected. Because of safety limitations and the potential for damage to rims, hub and studs, it was not possible to re-create the circumstances and conditions of the separation as part of the investigation in order to establish the level of noise or vibration generated by a loose rear wheel.

**Industry Practice**

It is not possible for there to be a single uniform practice for the tensioning of wheel nuts due to the variety of wheel fastener sizes and configurations used throughout the industry. However, there are certain principles that are crucial to maintaining tension on any fastener, including wheel studs and nuts. The crucial factor in determining the performance of wheel fastening systems is the clamping force with which the fastener holds the rims to the hubs. This relies on having adequate numbers and strength of fasteners all tensioned to specification.

In the automotive field, particularly with passenger cars, it is common practice for workshops to use an impact gun only when securing wheel nuts to cars. The problem with that practice is that it is very easy for insufficient or excessive tension to be placed on the stud. The impact gun is an unreliable tool for tensioning fasteners as the amount of torque achieved when using an impact gun varies depending on air pressure, air flow, the efficiency of the vane motor within the gun, time of engagement of the tool and its condition. The same applies in heavy vehicle applications.
2.35 Therefore, it is common for heavy vehicle wheel nuts, with their higher clamping force requirements, to go through an additional manual tightening process. This involves torque wrenches or bars with long handles. Some of the torque wrenches examined during the investigation had a lever length of approximately 1.5m, which, to produce a torque of 700Nm would equate to having to apply a weight of approximately 47kg to the end of the bar (47kg is the weight required to apply a force of 46N to the end of a 1.5m bar, producing a torque of 700Nm).

2.36 The lubrication of clean thread surfaces reduces the friction between the stud and the nut, providing greater clamping force when tensioned due to less friction. For example, if there was 20% of the torque used in overcoming friction forces, which some literature suggests is far less than the actual frictional losses, the clamping force would be a constant 20% lower than the torque being applied. Therefore, a torque wrench reading 700Nm of applied torque would only be applying 560Nm of torque with 20% frictional losses, resulting in 20% less clamping force. If the reduced clamping force falls at the lower limit of the stud’s elasticity, shear forces may result in the stud failing. The studs and the remaining wheel nut from this incident did not show any signs of lubrication having been applied (see Photo 14).
Photo 14: No evidence of lubrication inside wheel nut located after incident

Maintaining Integrity

2.37 For the wheel rims to stay secure to the hub there must be a constant clamping force provided by the fasteners. There are two primary factors relating to the fitment of wheels to ensure that this is achieved; one involves the studs being tensioned correctly, and the other is the absence of compression of the materials being clamped.

2.38 The correct tension is ensured through the use of calibrated equipment and low friction between fastener components. Absence of compression can only be achieved through having rims made of material capable of withstanding the pressure exerted by the face of the nut. Painted, rusted or otherwise contaminated rim surfaces can lead to fasteners loosening as the materials compress and disperse over time. If enough compressible material exists between the mating surfaces, stud tension may reduce to the point where the nut comes loose, eventually leading to failure of the connection.

2.39 Many of the buses examined had numerous layers of paint built up over time. While it was not a contributing factor in this incident, it should be a
consideration for wheel fitters when examining rims prior to mounting. *Photos 4 and 15* show the multiple paint layers on the outside of the rim. Also visible is the damage to the rim through fretting against the nut flange during service. *Photo 11* earlier, shows paint on the nut flange from a similar bus.

2.40 Another factor in stopping the wheel nuts coming loose is the close fit of the stud hole to the stud. Elongated stud holes will allow torque forces to move studs backwards and forwards within the hole, elongating the hole further and acting to loosen the nut (see *Photo 15*).

![Photo 15: Inside of outer rim showing elongated holes and at least two layers of paint once present](image)

2.41 The hub must register correctly against the inside of the rim, as this prevents the rim from moving vertically under load. Any movement of the rim encourages the loosening of nuts due to the cyclic stresses placed upon the stud. When tensioned correctly, the rims remain static.
2.42 As a result of the necessary conditions not being met, both the hub and outer rim of the bus’ rear wheel were damaged to such an extent that they had to be scrapped and replaced.

Remedial Actions

2.43 The Operator conducted an internal investigation which resulted in warning letters being issued to the employees involved for breaching policy by not re-checking the wheel nut tension. The incident was also the catalyst for the introduction of a wheel nut indicator trial which involved fitting plastic pointer tags to wheel nuts following tension. The aim is to produce a visual indication if nuts move from their original tensioned alignment (see Figure 3).

![Figure 3: Illustration of tags fitted showing no movement, then showing one nut out of alignment](image)

2.44 The use of pointer tags would appear to serve their purpose albeit at the expense of additional time and effort at wheel changing, and providing they are readily visible when checked. However, Westbus does have appropriate policies and procedures in place which, if adhered to fully, would serve to prevent the type of incident which necessitated this investigation. Further, these policies and procedures are better than those of several other operators whose procedures were examined. Additionally, manufacturers’ specifications and recommendations provide the procedures to be followed for safe practice.
Frequency of Incident Type

2.45 Since July 2004, ten incidents have been reported to OTSI which have involved wheels detaching from buses. It is probable that the actual number of loose wheel incidents is higher, as only reports of wheels coming adrift have been received. Instances of loose wheel nuts often get picked up during initial test drives and the problem rectified early.

2.46 Wheel separations from cars and heavy vehicles which do not result in a collision or injury would not normally be reported to Police. However, OTSI maintains visibility of incidents of this nature due to accredited bus operators being required to report such incidents.
PART 3  FINDINGS

Causation

3.1 The rear wheels of the bus were fitted by two mechanics using an impact gun. While the driver’s side rear wheel nuts were then tensioned manually with a torque wrench, the same procedure was not followed for the passenger’s side, resulting in the bus leaving the workshop with that wheel inadequately tensioned.

3.2 The bus travelled approximately 1,500km over eight days before the wheel separated from the vehicle, colliding with a stationary car. The loose wheel nuts were not detected and remedied during that period.

3.3 The last remaining nut holding the rim to the hub was torn from its stud as the bus approached Cowpasture Road, resulting in the rear wheel overtaking the slowing bus and colliding with the stationary car.

Contributing Factors

3.4 The Operator has appropriate policies and procedures in place for the task of tensioning fasteners as part of wheel re-fitting. They were not followed on this occasion due a miscommunication among depot workshop staff. If they had been followed, the incident would not have occurred. The Operator has addressed this matter with the staff concerned.

Other Safety Matters

3.5 There are a range of wheel fitment practices in place across bus depots, partly attributable to the fact that wheel fitment is considered a routine practice in itself as well as part of other maintenance and repair procedures. The more robust practices use a torque wrench in addition to an impact gun followed up with a wheel nut tension check after a road test.

3.6 Excessive paint build up on the mating surfaces of rims can lead to a loss of tension as the paint is compressed and worn away during vehicle operation. A number of rims examined during the investigation showed multiple layers of
paint on the mating surfaces of rims. Ideally, the rim surfaces should be free of any compressible material including paint, metal burrs and corrosion.

3.7 Lubrication of fasteners decreases the amount of friction between the nut and stud. Lubrication should be used to prolong the life of the threaded components as well as more accurately translating torque to clamping force. A number of wheel nuts examined during the investigation were found to lack any evidence of being lubricated.
PART 4 RECOMMENDATIONS

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

ComfortDelGro Cabcharge Pty. Ltd.

4.2 Ensure that the existing policy and procedures for wheel replacement are adhered to and supervised, with particular emphasis on second tension checks.

4.3 Review the adequacy of existing policies and procedures with regard to their reference to manufacturers’ recommendations, contamination of rim surfaces and lubrication of wheel fasteners.

NSW Department of Transport and Infrastructure

4.4 Ensure, through the Bus Operator Accreditation System (BOAS) auditing process, that accredited operators have in place and adhere to adequate, specific procedures for ensuring the correct tension is established and maintained on bus wheel fasteners.
APPENDIX 1: SOURCES AND SUBMISSIONS

Sources of Information

- ComfortDelGro Cabcharge (WestBus, HillsBus)
- Bonnyrigg depot staff
- TAFE NSW
- Shorelink
- State Transit Authority of NSW (STA)

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)

Submissions were received from both ITSRR and NSWTI.

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.