Annual Bus Roadworthy Inspections: Evidence-based assessment of impact of proposed inspection procedures on safety and cost

Report prepared for Road Safety Inspections

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1 Background

Both the safety and reliability of bus services call for the operation of mechanically sound vehicles that are free of defects and comply with roadworthy standards. Most countries around the world have implemented legislation requiring bus operators to maintain roadworthiness of their vehicle fleet while in service. In Victoria, Australia, bus operators need to ensure that their buses are roadworthy whenever they are carrying passengers (Bus Safety Victoria, 2017). Vehicle roadworthiness is heavily dependent on a high standard of vehicle maintenance (internal), as well as regular mandatory inspections of vehicle fleets (external). The mandatory independent inspection can be seen as an audit or compliance check of the maintenance practices implemented by vehicle operators (Canadian Council of Motor Transport Administrators, 2014b).

Mandatory roadworthy inspections are conducted annually on all buses operating in Victoria by Licenced Vehicle Testers (LVTs) under Regulations 214 and 220 of the Road Safety (Vehicles) Regulations 2009. VicRoads provides instructions for the conduct of inspections. In June 2020, a Directive Order (DO) was released by VicRoads superseding the instruction SOP001 with regard to brake inspections, with a focus on wheel removal and taking and storage of photographs. The new DO requires all LVTs to take a minimum number of photographs during the inspection procedure for all vehicle types. Regarding buses, a minimum number of 14 photographs for all buses is required, and for small buses[1], all wheels must be removed to check brake infrastructure (with photographic evidence). For heavy vehicles, either the wheels must be removed or backing plates removed to check brake infrastructure (with photographic evidence.)

1.1 Aim of the report

Road Safety Inspections (RSI) is one of the largest LVTs in Victoria and is committed to passenger vehicle safety. RSI note that the new DO was developed and released in the absence of industry consultation, with no indication of an evidence-based approach, and little appreciation of the potential safety and cost implications. RSI recognises the importance of a scientific approach, and the overall objective of this project is to provide an evidence-based assessment of the safety and financial implications of the DO.

1.2 Project work components

Four complementary work phases were undertaken, as follows:

- Desk-top Review: Assessment of current state of bus roadworthy inspection approaches;
- Review of available data: Review of incident and inspection data, and site visits;
- Cost-benefit analysis: Identification of costs and benefits of DO brake inspections;
- Synthesis of findings.

[1] A clear standard for distinguishing small and heavy buses needs to be provided, Appendix A1 vs Appendix A2.

2 Findings: Desk-top Review

The desk-top review incorporated a review of relevant national documents and comprised targeted searches of national, State/Territory government agency and relevant organisations' websites. Information was also sought during site visits to representative Victorian bus operators. Selected international approaches were also reviewed. The assessment sought to identify and document the following:

- Current regulations, directives and procedures regarding bus roadworthy inspections in Australian and international jurisdictions, focusing on brake inspection procedures.
- Comparisons of jurisdictional approaches.

2.1 Brakes on buses

Prior to describing current regulations and procedures, it is important to identify the types of brake systems that are used on buses and their structure and mechanism.

Large heavy vehicles like buses, trucks, and railroad trains are equipped with air brakes, which use compressed air to transmit the force applied to the brake pedal to the brakes and wheels, as opposed to the hydraulic brakes commonly used in automobiles, motorcycles, and light trucks, which use brake fluid to transmit force. Air brake systems have the following advantages with regard to safety performance: i) minor leaks do not result in brake failures; and ii) air brakes are effective even with considerable leakage, so an air brake system can be designed with sufficient "fail-safe" capacity to stop the vehicle safely even when leaking (Wikipedia, 2021).

2.1.1 The structure and the mechanism

There are generally two types of brakes (disc and drum) and there is a mixture of them in the Victorian bus fleet. As the structure and mechanism of the two types of brakes are fundamentally different, it is important to establish a functional understanding of the two before assessing inspection procedures.

As illustrated in Figure 2-1, a drum brake consists of the brake drum and a set of brake shoes, which have the heat-resistant friction material bonded to them. When the brake pedal is pressed, the movement is transferred to force the shoes against the drum, develop the friction torque and slow the wheel (Childs, 2014).

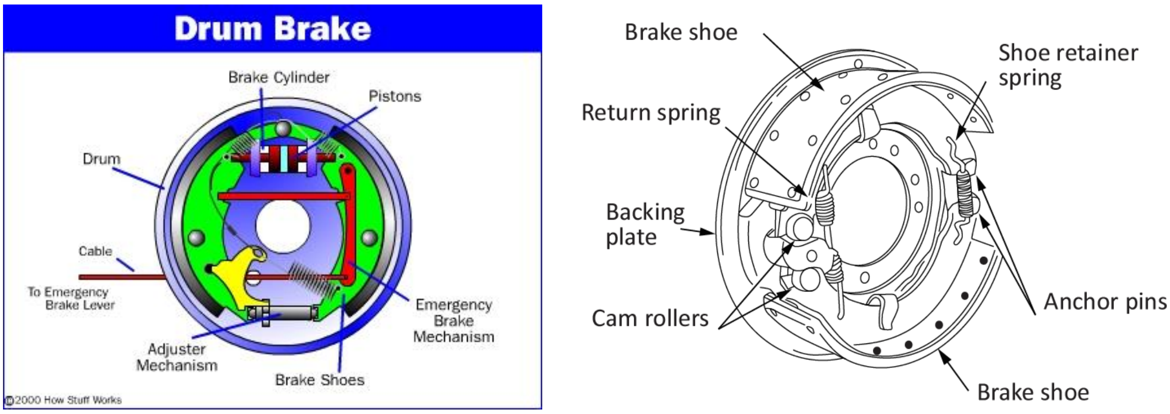


Figure 2-1 Illustration of the structure of drum brakes

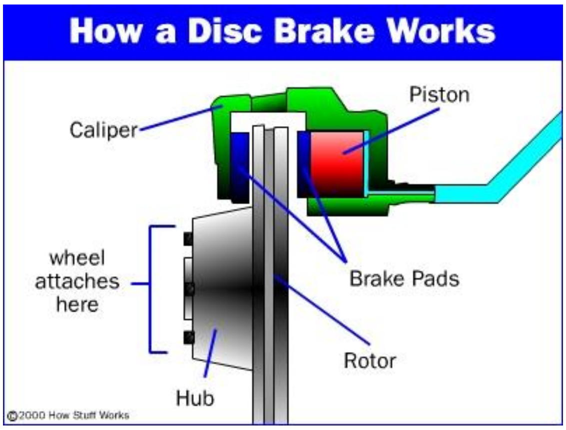
Source. How Stuff Works[1] & National heavy Vehicle Regulator (2020)

Figure 2-2 illustrates typical drum brake and wheel maintenance at a large Victorian bus operator (Dyson Group).

Figure 2-2 Drum brake and wheel maintenance at representative Victorian bus depots

Disc brakes typically consist of a disc or rotor, which is sandwiched between two pads actuated by piston(s) supported in a caliper. When the brake pedal is pressed, compressed air is forced into the cylinders, pushing the opposing pistons and brake pads into frictional contact with the disc. Disc brakes have the advantages of steady braking, easy ventilation and heat dissipation, and simplicity of maintenance (Childs, 2014; KMDB Manufacturers, 2015) and have been increasingly adopted in the bus fleet. All new buses destined for the UK market are 100 percent disc brake-based (Chris Tindall, 2019). A similar trend is witnessed in Victoria, Australia. Figures 2-3 and 2-4 illustrate the structure of a disc brake and typical wheel maintenance.

[1] https://auto.howstuffworks.com/auto-parts/brakes/brake-types/drum-brake1.htm



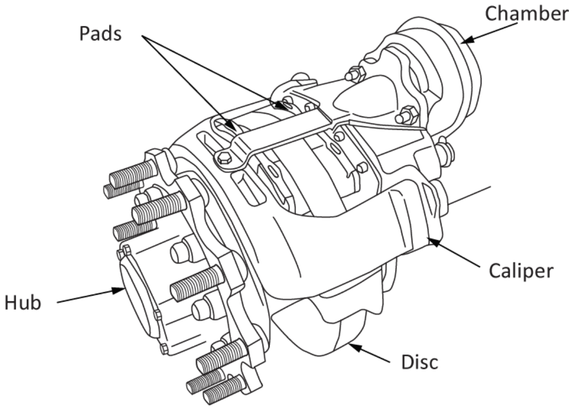


Figure 2-3 Illustration of the structure of disk brakes

Source. How Stuff Works[1] & National heavy Vehicle Regulator (2020)

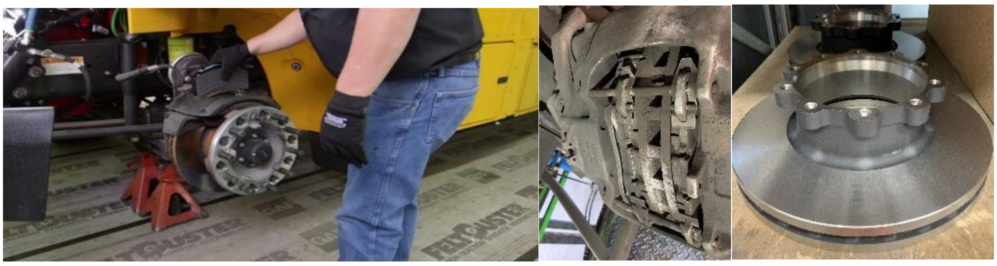


Figure 2-4 Disc brake and wheel maintenance at representative Victorian bus depots

2.1.2 The distribution of disc and drum brakes in Victorian bus fleet

According to practitioners in the field (fleet managers at bus depots and inspectors), there are various combinations of brake set ups in the fleet in the Victorian bus fleet: front and rear disc brakes (newer), front disc and rear drum, and front and rear drum (older). Most modern vehicles (buses manufactured in the last decade) are fitted with disc brakes both at the front and rear.

2.2 International benchmarking of heavy vehicle brake inspection practices

The inspection procedures in Australia, Europe, UK, Canada and the US were examined to acquire a comprehensive understanding of the procedures and practices in brake inspection.

Australia

There is no clear indication regarding this matter in the "National Heavy Vehicle Inspection Manual" and the tests and measurements specified in the Manual (as summarised in Appendix B) would not necessitate wheel disassembly (National heavy Vehicle Regulator, 2020).

The linings can be visually inspected through the brake drum backplate inspection cover (peep hole), which is a universal and time-honoured process to assess the state of wear for drum brakes and can detect most brake shoe wear (Dalrymple, 2020). Most disc rotor and brake pads wear can be inspected by looking through the wheel rim holes or from under the bus using a set of gauges, as illustrated in Figure 2-5.

[1] https://auto.howstuffworks.com/auto-parts/brakes/brake-types/disc-brake1.htm

Figure 2-5 View of brake pads wear through wheel rim holes

Europe

As specified in “Periodic Roadworthiness Tests for Motor Vehicles and Their Trailers” regarding the methods of testing, the tests shall be carried out using techniques and equipment currently available without the use of tools to dismantle or remove any part of the vehicle (The European Parliment & The Council of the European Union, 2014). The specifics are summarised in Appendix B.

UK

According to “Public Service Vehicle Inspection Manual”, the procedures assume that only parts of a vehicle which can readily be seen without dismantling are to be examined. In cases where the wheels of vehicles cannot be seen completely from ground level, especially with twin wheels and part of the wheels are hidden by the body, the vehicle must be moved to expose hidden parts of the wheels, or examined from underneath. It may be necessary to ask the presenters to remove wheel embellishers (aka hub caps), wheel trims, panels, or visual security indicators if they prevent a full examination or it is not otherwise possible to inspect safety critical items. However, wheel nuts and studs must not be removed to check compatibility (Driver & Vehicle Standards Agency, 2018).

US

Similar to Australia, there is no clear indication regarding this matter in the “Code of Federal Regulations” in the US. However, the tests and measurements specified in the “Minimum Periodic Inspection Standards” (as summarised in Appendix B) would not necessitate wheel disassembly (Federal Motor Carrier Safety Administration, 2011). Visual inspections of brakes and wheels can be speculated from the specifications in “Vehicle Inspection Operations & Training Manual For Official Vehicle Inspection Stations”. These note that the inspection of all wheels and rims will be visual and wheel covers or hubcaps may be removed from the vehicle if the certified inspector has probable cause or reason to believe that wheel or rim defects exist (The State of Texas, 2019).

Canada

Canada provides the most comprehensive procedures for brake inspection. Conditional wheel disassembly was introduced in 2014 and is described in the “Periodic Commercial Motor Vehicle Inspection Standards”[1] (Canadian Council of Motor Transport Administrators, 2014b). It is

[1]National Safety Code Standard 11 Part B

noteworthy that the bus operator and inspector industry believed these changes would make inspections longer, and more expensive.

Drum brakes: There are three types of inspections specified for drum brakes, as follows:

- (A) Full inspection with drum removed: this is a detailed inspection of all internal components and includes measuring the internal diameter of brake drum and thickness of the thinner brake shoe lining.
- (B) Wheel-on full inspection: this is only available for cam-type drum brakes with removable dust cover/shields and involves an inspection of internal components with dust cover/shields removed, including measuring drums and shoe lining.
- (C) Limited inspection of drum brake: this is an inspection through inspection holes and involves a measuring of shoe lining only. Buses with drum brakes, only qualify for a limited inspection for 7 months after completing a “Full inspection with drum removed”, and only when such inspection is properly documented.

Disc brakes: There are two types of inspections for disc brakes.

- (D) Full inspection with wheels removed: this is a detailed inspection of all components and includes measuring the thickness of the rotor and the thinnest pad friction material. Disc brakes require a full inspection with wheels removed at least every 12 months.
- (E) Limited inspection of disc brake: this is an inspection of visually accessible components and measurement of the friction material of one brake pad (usually the inner one). When a full inspection with wheels removed is conducted on a disc brake and proper documentation is completed, the brake can qualify for a limited inspection for a period of 7 months.

The Canadian procedure also provides for an evidence-based approach for suspecting a brake defect. It is specified that full inspection with either drum or wheel removal is required only when any defect is suspected or found during an inspection. Suspecting a defect of any wheel brake must be based on some visible evidence that could indicate the presence of a problem or abnormal condition, including the following: abnormal wear of the brake drum or rotor; abnormal wear of friction material; abnormal appearance, glazing, discolouration or contamination of brake friction material; damage, distortion or shifting out of place of any brake component; evidence of negative effects of corrosion; signs of overheating; abnormal noise or response upon application or release of the brakes; the age of the brake components, or the previous measurements of wear compared to current measurements, indicating that a drum, rotor, or friction material, is likely to be worn beyond the allowable limit.

Background context: In addition to providing a description of the Canadian procedure, it is also important to review the context background and motive of the introduction of conditional wheel disassembly in 2014. Canada, fitting in the framework of Commercial Vehicle Safety Alliance (2021), had an ongoing history of monitoring brake condition among commercial vehicles via annual road checks, dating back to 1998. According to the yearly roadside inspections, brake-related defects continued to account for around half of all out-of-service violations in 2008, 2009, 2010, 2011 and 2012 (Canadian Council of Motor Transport Administrators, 2007, 2009, 2012, 2008, 2010, 2011) and constantly represented the single most prevalent Out-of-Service (OOS) violation in 2013 and 2014 (45%) (Canadian Council of Motor Transport Administrators, 2013a, 2014a). Brake Safety Week had been actively and continuously campaigned among governments, industry associations and individual carriers and drivers as an effort to achieve a substantial drop in the brake OOS rate. Hence, it is speculated that the introduction of the wheel disassembly procedure into periodic motor vehicle inspections (PMVI) corresponded to the long-term struggle and attempts to improve brake condition.

Regarding the inference of the effects and implications of the amendment, a review of the rates of brake-related defects after the introduction of wheel disassembly in PMVI was considered worthwhile. According to the annual road check statistics, brake-related defects accounted for 39%, 46%, 48% and 44% of all OOS violations in 2015, 2016, 2017 and 2018 respectively (Canadian Council of Motor Transport Administrators, 2015, 2016, 2017, 2018), suggesting that, despite the introduction of the directive, brake-related defects continued to comprise nearly half of all OOS violations cited during roadside inspections. Confined by the information and data available, it is difficult to decide whether the introduction of conditional wheel disassembly had any effect on brake compliance. Information of clarity, data of accuracy and solid research evidence are needed to provide a robust evaluation of the impact. In addition, it is important to note that the sample was heavily overrepresented by trucks and the rate of OOS buses with brake defects is unknown (Appendix C).

2.3 Summary of inspection methods & critical measurements

The review of international practices regarding inspection of heavy vehicle brake function revealed a range of procedures and measurements. The key findings were:

- The European Union and UK specify that inspections should be conducted without dismantling or removing any part of the vehicle and to examine only parts of a vehicle which can readily be seen.
- UK specifically states that wheel nuts and studs must **not** be removed.
- The US procedure is unclear, however specifies that inspection should be visual unless there is probable cause or reason to believe there are defects, and in these cases the wheel covers or hubcaps may be removed.
- The current approach in Australia is similar to that in the US.
- In contrast, Canada introduced a conditional wheel disassembly approach in 2014 in response to a high proportion of brake-related defects contributing to OOS. Wheel removal depends on the type of brakes being inspected, the type of inspection previously completed and whether there are signs of brake defects.
- A comparison of brake-related defects prior to and following the new Canadian procedure revealed no reduction in these violations. It is also noted that trucks were over-represented in the sample.
- The major difference between wheel on and off inspections is that in the jurisdictions (EU, UK, US & Australia) and circumstances (Type C & E in Canada) where wheels stay on during inspections, the inspection is more qualitative, while in situations where the wheels are taken off (Type A & D in Canada), the inspection has a quantitative focus, including the measurements of drum diameter & brake shoe lining thickness (for drum brakes) and rotor thickness and pad friction material thickness (for disc brakes), as summarized in Appendix B.

Based on the available evidence regarding current procedures, it may be concluded that visual inspections would suffice in Australia, unless there are reasons to suspect defects.

2.4 Additional findings: alternative approaches

In addition to the review of current inspection practices nationally and internationally, the desk review revealed information regarding practices of brake and wheel inspection in other transport modes including rail and aircraft. These approaches were investigated to complementation and reference.

Non-destructive testing (NDT) including ultrasonic testing (UT), eddy current testing (ECT), magnetic testing (MT), X-ray and radiation testing (RT), is a practical technique for detecting, locating, measuring, and assessing the internal hetero structure of components. This technique has emerged as a popular practice in post-maintenance in the automotive and aerospace industry due to its advantages such as maintaining high efficiency without compromising effectiveness and reliability, enabling a more frequent integrity control and reducing inspection and maintenance costs (Du, Zhao, Roy, Addepalli, & Tinsley, 2018).

NDT technology has been developed and widely used to monitor and diagnose the aspects of train wheels including rim volume, wheel diameter, wheel flats and cracks during operations (W Kappes et al., 2000; Wolfgang Kappes et al., 2007; R. Pohl, A. Erhard, H.-J. Montag, H.-M. Thomas, & H. Wüstenberg, 2004; Tsompanidis & Tsiakas, 2007). To enable the inspection of the wheels (rim and disk) without dismantling the wheels, R. Pohl, A. Erhard, H. J. Montag, H. M. Thomas, and H. Wüstenberg (2004) proposed ultrasonic testing (UT) techniques which carry out the inspection using a multi-probe arrangement. Hwang, Lee, and Kwon (2009) proposed a scan-type magnetic camera to detect and evaluate cracks on train wheels with high-speed and high spatial resolution. To detect railway wheel flats, the most common local surface defects in railway wheels, Brizuela, Ibañez, and Fritsch (2010) developed an NDT system, which sends ultrasonic surface wave pulse at regular intervals, acquires and then processes the echoes. Li, Zuo, Lin, and Liu (2017) proposed and employed an algorithm for adaptive multiscale morphological filtering to facilitate railway wheel flat fault detection. Using this technology allows assessment and differentiation of the axle box vibration that is caused by wheel flats from the influence of track irregularity and vehicle running speed. Torabi, Mousavi, and Younesian (2018) proposed a machine-vision-based approach to perform the wheel diameter measurement, which is proven efficient, accurate and reliable. The system is based on the modification of three-point radius measurement technique and the development of appropriate image processing that decreases the steps in conventional third point calculation to save time and enable fast operation.

NDT is also commonly applied to reveal the failures of components in the aircraft sector. Kosec, Kovacic, and Kosec (2002) described revealing and identifying a fatigue crack on an aircraft wheel rim using eddy current technique. Amura, Allegrucci, De Paolis, and Bernabei (2013) demonstrated the sensibility of ultrasound tests to detect fatigue cracks and monitor the wheel structural integrity of AMX main wheels.

A range of NDT techniques have been developed and applied in the rail and aircraft sector to monitor the condition and detect the defects of wheel components, which may be considered for the bus sector.

In addition to alternative approaches in other transport sectors, the review revealed al alternative test within the bus sector.

For disc brakes, an emerging method available for monitoring pad thickness is electronic pad wear sensors. According to Sam Distefano, Group Manager Fleet Services at Dyson, and Brett Gibbs, General Manager at Road Safety Inspections, most modern vehicles are fitted with disc brakes at the front and rear and have brake pads wear sensors to indicate brake pad wear (roughly 2010 onwards). There are generally two different types of pad wear sensors, one with a simple on/off switch that illuminates a warning light on the dash panel when the pads need changing (end-of-life sensor), and the other with a continuous wear sensor providing feedback to the vehicle's electronic control unit throughout the pad life (potentiometer sensor) (American Public Transportation Association, 2017a). In view of the shift to disc brakes during the last decade and years to come, pad wear sensors may be a useful tool to monitor wear and brake friction material.

Figure 2-6 Disc brake wear indicators

3 Findings: Data analysis and site visits

While a rapid review of published and grey literature was proposed, a search of the databases and search engines available through the Monash University library revealed very little relevant literature. As an alternative, data sources available to the research team were accessed and site visits to bus operators and RSI were conducted in order to address the following:

- Association between inspection procedures and safety outcomes
- Best-practice approaches to heavy vehicle/bus roadworthiness and periodic inspection procedures
- Best practice inspection methods (with a focus on methods to check vehicle brake integrity)

3.1 The prevalence and nature of brake defects

Building on the experience from Canada, the research team investigated the Victorian bus inspection and incident records to establish an understanding of the prevalence and nature of brake defects among Victorian buses.

3.1.1 Among bus incidents

Among the 176 bus incidents (mechanical failures (N = 84) and fires (N = 92)) reported during 2012-2018 in Victoria, 17.6 percent (31 incidents) could be attributed to brake-related defects. Table 3-1 presents a brief description of these incidents.

It is worth mentioning that as the air brake system is designed in a "fail-safe" manner, these brake failures result in slowing or stopping the buses instead of having them in motion without control, which posed a less harsh threat to safety.

The most common failures with brakes were faulty brake calliper (seized), brake dragging, sticking, binding and locked/held on.

In view of the scarce number of reported bus incidents in Victoria, the research team examined the statistics from a neighbouring jurisdiction to enrich the context. In NSW, there were 43 reported fire and thermal incidents in 2020 that originated in the wheel well area and were a result of brake issues. A brief illustration of these incidents is presented in Appendix D. The brake failures in NSW were quite similar to those in Victoria and the majority of them had the following causes: faulty brake calliper, worn park brake valve, faulty brake booster, faulty slack adjuster, and incorrectly adjusted brakes.

Among the Victorian brake incidents with information on the defective brake/wheel (N=19), 12 of them involved rear brakes. For the thermal incidents involving brakes (N=43) in NSW, 30 were rear. It seemed that rear brakes were more prone to failure. One possible explanation is that the rear wheels, especially those of route service buses, predominately work in congested residential areas with narrow roads where the rear wheels keep hitting the kerbs and roundabouts.

Table 3-1 Common brake defects in reported bus incidents

Description	F/R
Brake fade caused by brake line leaking fluid	NA
Leaking brake fluid	NA
Seized wheel calliper, smoke coming for NSR wheels	R
Seized brake calliper causing NSR tyre fire	R
Brake seizing causing smoke at OSR wheels	R
Brake locked NSR, causing small fire in wheel area	R
Brakes were locked and smoke from the OSR wheel	R
Brake lock-up	NA
Brake locked on and caught on fire	NA
Rear brake drag and lock up, brake lining has been lightly touching the brake drum	R
Brake calliper binding, NSR brake dragging, brakes caught fire	R
Front brake sticking causing smoke	F
Brake calliper held on which caused NSF brakes to heat up	F
Brake calliper failure, smoke in the vicinity of the NSF wheel	F
Brake calliper failure, smoke emanating from the NSR wheels	R
Brake calliper fire (OSF) caused by a failure of an internal bushing	F
Brake calliper was loose due to the rotor bolts not tensioned to the correct tension	NA
Possibly a loose brake calliper or drum.	NA
Low air pressure caused heat from brake drum NSR	R
Brake booster fault, brakes locked and smoke	NA
Fire emanating from brake pads on rear wheel of bus	R
Rear brake failure causing smoke	R
Brake fire NSR	R
Smoke at NSF wheel	F
Brake failure at OSF causing smoke	F
Both front wheel hubs caught fire	F
Smoke coming from brake drum	NA
Brake shoe on fire	NA
Smoke filled the inside of bus due to issue with the brakes	NA
Brake failure	NA
Parking brake	NA

3.1.2 Among annual inspections

Table 3-2 shows the failure rates of bus components during annual bus inspections.

Regarding the magnitude of brake failures during annual inspections, among the buses run by accredited operators in Victoria, approximately 5.4 percent[1] of the annual inspections (N=24,310)

[1]The numbers do not add up to 5.4% as a bus inspection can fail in more than one category.

failed in brake related components during 2014 - 2018 (containing Service Brakes (4.1%), Brake Performance (1.5%) and Parking brake (0.6%)) (Table 3-2).

Table 3-2 Failure rates of bus components during annual bus inspections (2014-2018, Victoria)

Level of safety risk	Bus components inspected	Failure rate (%)
	Overall	17.9
High	Steering & Suspension	6.8
	Body & Chassis	6.2
	Engine & Driveline	5.0
	Service Brakes	4.1
	Brake Performance	1.5
	Wheels & Tyres	1.2
	Seats & Seatbelts	3.1
Medium	Lamps, Signals & Reflectors	5.9
	Windscreen & Windows	1.6
	Windscreen Wipers & Washers	1.3
	Parking Brake	0.6
Low	Exhaust emission controls	1.3
	Other items	4.4
	Modifications	0.2

To gain a more in-depth understanding of the mechanism of brake failures, the RSI dataset was examined, which documents the details about the subcomponents that contribute to brake failures. The RSI checklist is presented in Appendix E.

First, the number of failed Brake Performance was examined. Among the 61,644 bus inspections RSI conducted between 2011 and 2020, 1,225 (2.0%) failed Brake Performance and the distribution by wheel position and severity of failure is shown in Figure 3-1. Approximately half (46.8%) of those that failed Brake Performance had issues with rear near side brakes and around 40 percent were rear off-side brakes. The finding that the most prevalent brake inspection failures were with rear brakes is consistent with the incident data that rear brakes were more prone to break down.

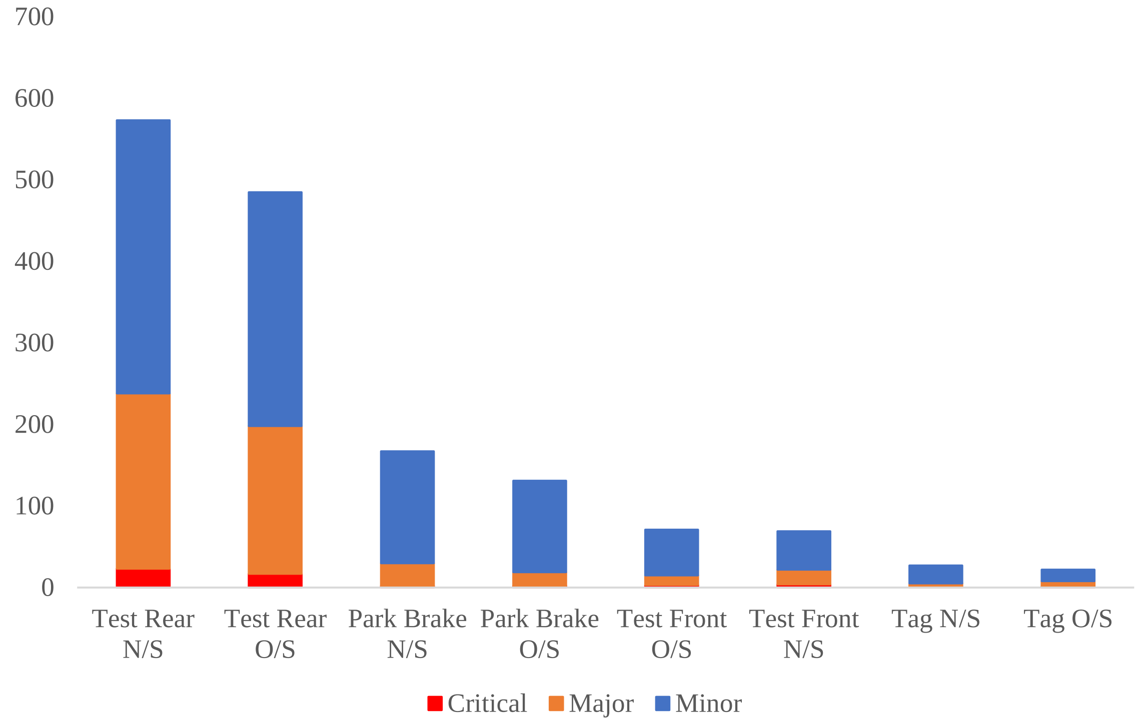


Figure 3-1 The distribution of failures among Brake Performance by fault type and severity

In addition, the frequency of failures among Service Brakes was examined and the distribution of these failures by fault type and severity of failure is presented in Figure 3-2. During the 10-year span, 2,504 (4.1%) of the inspections failed Service Brake, among which, 50.2 percent had issues with Air/Vac leak, making it the most prominent brake defect. This finding is consistent with the quote from Sam Distefano, Group Manager Fleet Services at Dyson that the common brake defects that contribute to bus in-service breakdowns and incidents are air leaks and self-adjusting mechanisms failing at times.

Only five critical failures were found, for air/vac leaks and lines/hoses (1 each) and slack adjusters (n=3).

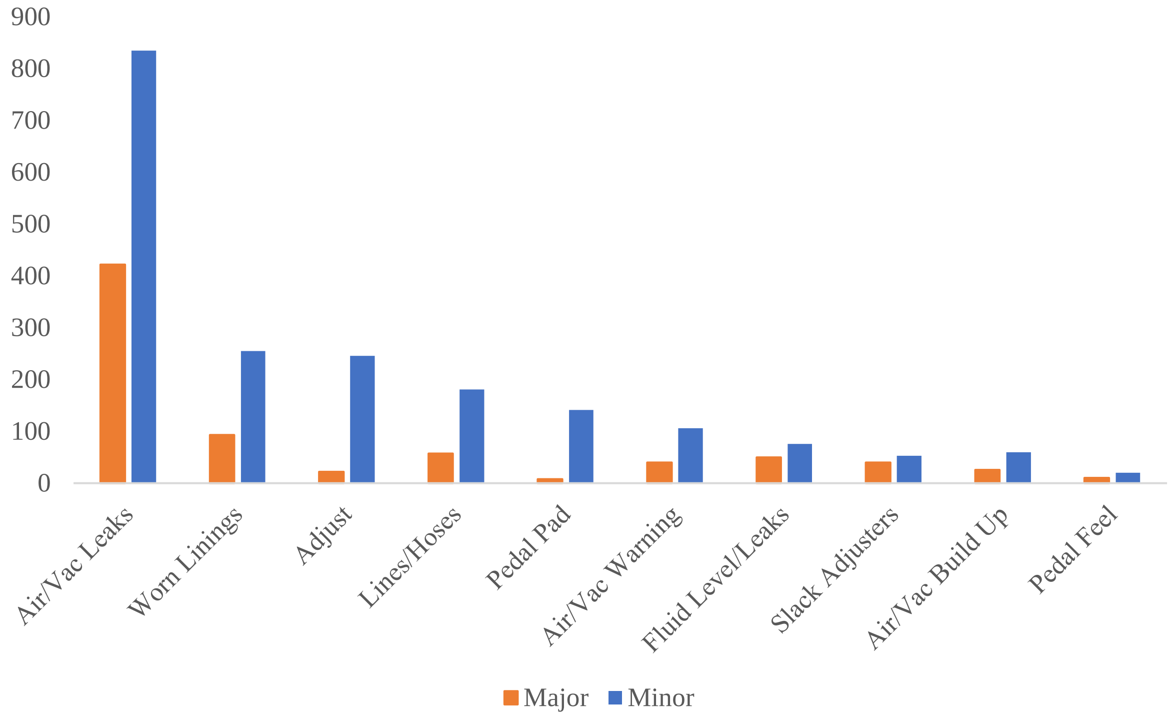


Figure 3-2 The distribution of failures among Service Brake by fault type and severity

3.1.3 Among roadside inspections

According to the National Heavy Vehicle Baseline Survey conducted in 2017, the vast majority (90.1%) of buses/coaches inspected passed the brake efficiency test (i.e., they reached the minimum 4.5kN/tonne level as measured for a vehicle unit in the roller brake test) (National Heavy Vehicle Regulator, 2017).

Transport Safety Victoria conducts regular compliance activities to monitor the condition of the Victorian bus fleet. Table 3-3 provides a summary of compliance activities over a four-year period.

Examining the summary of activities between 2016 – 2019, out of the 1,376 buses and 15 trailers inspected, defective brakes were not identified as a safety concern. More in-depth statistics from TSV (if available) may shed light on the brake condition regarding the prevalence and nature of brake failures during roadside inspections.

Table 3-3 Summary of compliance activities by Transport Safety Victoria

Date	Location	Types of defects	Buses inspected
Oct, 2016	Geelong Cup	Zero. There was no mention of unroadworthy buses.	
Nov, 2016	Melbourne Airport	Two buses were issued with defect notices for unroadworthy items including tyres and suspension.	44
		21 trailers were issued defect notices for unroadworthy items including worn or insecure couplings, inoperative lights and worn tyres.	
Nov, 2016	Dunkeld Races	Zero. There was no mention of unroadworthy buses.	23
Jan, 2017	Phillip Island	Six buses were issued with defect notices (buses and trailers)	75
Feb, 2017	Twelve Apostles	17 buses were issued with defect notices (buses and trailers)	86
Apr, 2017	Robinvale	One bus was issued with a defect notice for frayed seat belts	22
Apr, 2017	Swan Hill and Bendigo	Zero. No mention of unroadworthy buses	42
May, 2017	Melbourne Airport	Eight buses issued with defect notices for worn tyres, brakes and glazing	31
		Five trailers issued with defect notices for warn tyres, wheel bearings and couplings	15 trailers
Sep, 2017	Phillip Island	The vast majority were compliant, with only two issues raised	22
Nov, 2017	Dunkeld Cup	Two buses with mechanical issues were warranted defect notices	52
Nov, 2017	Twelve Apostles	Zero. No mention of unroadworthy buses.	50
Dec, 2017	Northern Victoria	One bus was found to be fitted with two front tyres in a unroadworthy	117
Jan, 2018	Geelong	Zero. No mention of unroadworthy buses	55
Jan, 2018	Mildura	Zero. No mention of unroadworthy buses	49
Feb, 2018	Phillip Island	44 defect notices for problems including worn tyres, faulty seat belts, cracked windscreens, and suspension issues.	350
	Twelve Apostles		
Nov, 2018	Dunkeld Races	A number of defect notices were issued for buses that were found to be defective.	35
Nov, 2018	Twelve Apostles	Two defect notices were issued for buses which did not meet required standards.	31
Feb, 2019	Twelve Apostles	20 vehicles with defects, resulting in one bus being grounded	147
Feb, 2019	Phillip Island	Four vehicles with defects One trailer defective, resulting in it being grounded	87
Jun, 2019	Rutherglen Winery	12 defect notices for problems including worn tyres, cracked windscreens, inoperative headlights, and oil leaks	58

3.1.4 Summary of brake defects among inspections and incidents

Summing up, the magnitude of brake defects among Victorian bus fleet, either detected during inspections or those contributing to incidents was extremely small. Rear brakes appeared to be more vulnerable than front brakes to defects as they contributed to the majority of brake failures.

3.2 Site visits: Brake inspection procedure and practices

To better understand current annual bus inspection practices and comparing the processes involved in wheel-on and wheel-off brake inspections, the team made site visits to two bus inspection depots. The two depots were selected as they were ranked as the Best Performers regarding the fleet roadworthy performance (Qiu, 2020).

3.2.1 Wheels-on inspections

Current practice at RSI is to inspect brakes and brake performance with the wheels on, unless there is reason to suspect a defect or poor performance. Inspections with the wheels on is a relatively straight-forward process, and conducted using pits. The inspection can be described as ‘qualitative’ and, as noted in previous sections, the design of the wheels and brakes allows an appropriate visual inspection to be conducted. Figure 3-3 illustrates the current wheels-on procedure at RSI.

Figure 3-3 Current wheels-on inspection procedure at RSI

3.2.2 Wheels-off inspections

In the event that a brake defect is suspected, wheel-off inspections will be conducted. The procedures and practices of wheel disassembly, brake inspection and assembly are substantially more complicated than the wheels-on procedure, and are summarised below.

3.2.2.1 Wheel removal preparation

1. Park the bus at a service bay with under-bus access (equipped with a pit or hoist), support the bus on jack stands and jack the bus up to create a gap between the tyre and the ground.
2. Release the parking brake.

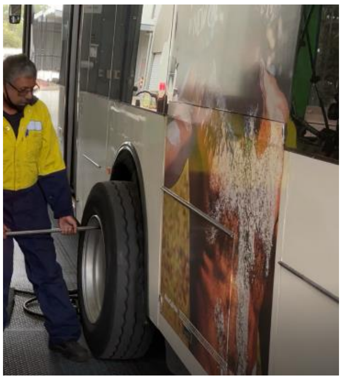
3.2.2.2 Wheel disassembly procedure - Rear drum brake

1. Remove the RipClips or Squirrel on rear wheels



2. Loosen the wheel nuts using the impact gun

3. Pull the wheels off with a lever



4. Adjust the slack adjuster so that there is maximum clearance between the brake shoes and the brake drum

5. Fit the release bolts


6. Use a lifting device (wheel hoist trolley) to pull off the brake drum


3.2.2.3 Brake inspection procedure – Rear drum brake

1. Measure brake shoe lining thickness

The above can be approximated by using a wire detector from underneath the bus.

2. Inspect the drum thoroughly.
3. Clear the dust in the drum

3.2.2.4 Wheel assembly procedure – Rear drum brake

1. Put the drum back on



2. Put the wheels back on


3. Screw the wheel nuts



4. Use a calibrated torque wrench to tighten the wheel nuts to the correct torque, as specified by the manufacture.


3.2.2.5 Wheel disassembly procedure – Front disc brake

1. Remove the RipClips (if applicable)

2. Loosen the wheel nuts using impact gun


3. Pull the wheels off with wheel hoist trolley


3.2.2.6 Brake inspection procedure – Front disc brake

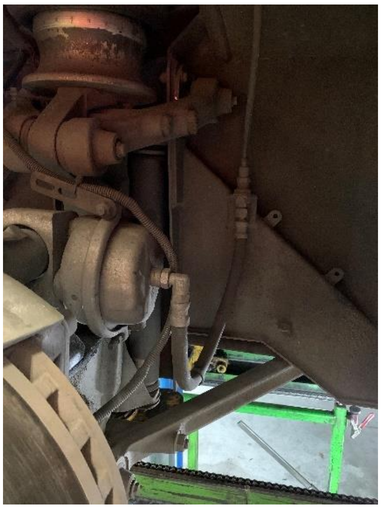
1. Measure the rotor thickness using vernier caliper (digital).

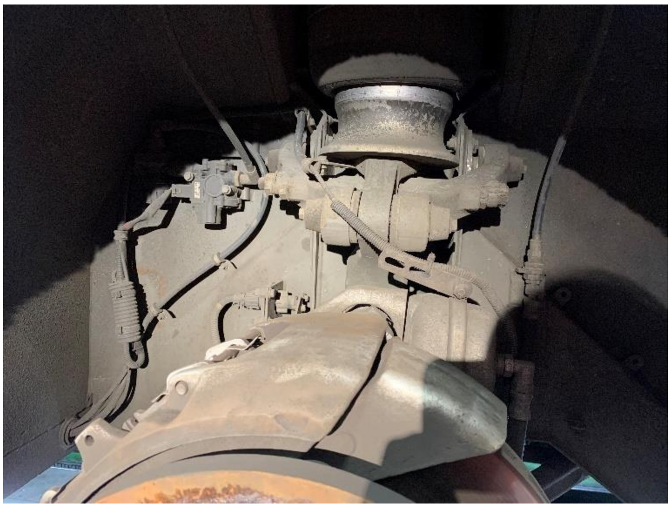
The measurement can be achieved from underneath the bus, without dismantling the wheel.


2. When wheels are removed, pads can be measured directly to achieve an accurate pad thickness measurement.

   With wheels staying on, the pad thickness can be inspected by reading the visual indicator (mark) or at the vehicle's electronic control unit fed by the pad wear sensor.

3. Inspect brake lines and hoses



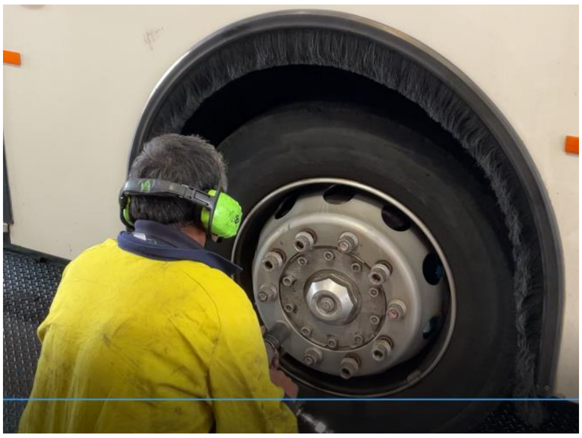


3.2.2.7 Wheel assembly procedure – Front disc brake

1. Put the wheels back on




2. Screw the wheel nuts

3. Use a calibrated torque wrench to tighten the wheel nuts to the correct torque, as specified by the manufacture.

3.2.2.8 Wheel assembly aftermath

Take a road test and retention the wheel nuts

Following wheel disassembly and assembly, the bus is required to take a road test, travel a certain distance, depending on manufactures' recommendation (e.g. up to 500kms), then return to the workshop for wheel nuts re-tension. Following that, nut markings need to be repainted and wheel nut locking devices be fitted.



A road test and the consequent torque check (retightening wheel nuts) following the wheel change is an important aspect in ensuring proper clamping force on wheels. A low clamping force by the wheel studs and nuts leads to nut detachment or stud fatigue fracture. Therefore, a torque check is essential in preventing wheel separations on buses (Bailey & Bertoch, 2009), which can have tragic results when these heavy wheel assembles (between 70 – 90 kg) collide with other vehicles, people, or roadside objects (Bailey & Bertoch, 2009; Monster & Eng, 2004). There were nine reported incidents involving loose wheels, wheel nuts and wheel detachment during 2012-2018 in Victoria (see Appendix F for details).

Overall, the disassembly and assembly of wheels during inspections should require additional 1.5 h per bus (an average).

It is worth noting that the above demonstrates the most typical brake structures in the Victorian bus fleet. For some medium-sized buses, the task of rear wheel disassembly and assembly is associated with increased complexity, including removing the hub and the drum assembly, ensuring correct replacement of wheel bearings, and associated issues, therefore require more time, and generate the need for additional training. An example is the Toyota Coaster. The dual wheel setup, nut surfaces that contact the rim and wheel bearings are complex structures that requires substantial effort to remove and re-assemble the wheels. An example of the Toyota Coaster drum brakes structure is provided in Figure 3-3 below.

Figure 3-3 Structure of Toyota Coaster rear drum brake.

3.2.3 Summary of site visits

To summarise, most of the brake inspections and measurements can be conducted or approximated while having the wheels on, with the major differences being qualitative vs quantitative and accurate vs estimate, which is consistent with the benchmarking of international practices. The question remains as to the marginal safety benefits the quantitative measurements bring.

4 Findings: Costs versus benefits

Following the findings of the desk review, data analysis and site visits, a comparison of benefits versus costs of mandatory wheel removal during brake inspections was undertaken. It is noted that an extensive Cost-Benefit-Analysis is beyond the scope of this project, as many of the costs and benefits, particularly safety-related factors, are not quantifiable without an in-depth analysis. Notwithstanding, this section outlines the evidence regarding the identified costs and benefits.

4.1 Potential benefits

The assessment included factors related to the following:

- Road safety/Incident reduction
- Inspection reporting
- Service reliability
- Vehicle factors
- Operational factors (financial costs)

4.1.1 Road safety/Incident reduction

To estimate the potential safety benefits of wheel disassembly during annual inspections, i.e. eliminating brake defects, a comprehensive understanding of the brake defects contributing to inspection failures and incidents need to be achieved.

Incident wise, according to the bus incident record (2012-2018), there were 31 brake-related incidents, in-service breakdowns mostly, and faulty brake caliper (seized), brake dragging, sticking, binding and locked/held on appeared to be the most common defects contributing to incidents. However, due to the lack of in-depth incident investigations, and therefore solid evidence on the radical causes of these brake defects, it is extremely difficult to decide whether these defects can be rectified by wheel disassembly.

Inspection wise, around four percent of the inspections failed Service Brake and air leak was the most common defect (accounting for 50.2%). Around two percent of the inspections failed Brake Performance and issues with rear brakes were the most prominent (46.8% near side and 39.6% off side).

4.1.2 Inspection reporting

It was suggested by VicRoads that the introduction of the DO to mandate wheel disassembly during annual inspections would result in a streamlined approach to the reporting system, particularly align with an online system for uploading photos and inspection outcomes. In addition, wheel disassembly during bus inspections would align more closely with inspection practices for other vehicle types (e.g., passenger vehicles). Notwithstanding these advantages, these benefits are not quantifiable.

4.1.3 Other factors

Regarding the other factors, including service reliability, vehicle improvements, and operational factors, no benefits were identified.

4.2 Potential costs

4.2.1 Vehicle-related factors

A number of vehicle-related risk factors were identified, as follows:

- Introduce the potential of vehicle damage and incidents. For instance, the practice will increase the risk of wheel nuts not being tensioned properly and the consequent risk of damaged wheel studs, nuts, wheels coming loose, wheel detachment in service and collision with other road users and objects.
- Disturb the brake shoe alignment on some drum brake vehicles and result in brake shudder. Some buses such as Scania and Mercedes tend to suffer from brake shudder after removing the wheels, thus requiring full brake realigning and re-adjusting (more time and costs).
- Wear and tear to wheel nuts and studs.

While it was not possible to link these vehicle-related risk factors to safety (evidence unavailable), it is entirely possible that there would be some associated safety risks.

4.2.2 Labour and capital costs for inspectors

A number of costs were identified. The costs are estimated based on procedures specified by Original Equipment Manufacturer (OEM) (SCANIA, 2006) and practices within (Dyson Bundoora and CDC Oakleigh depot) and across jurisdictions (American public Transportation Association, 2017b).

- Currently, it takes two staff between 0.5 -1 hour (depending on the size of the bus and the number of defects) to perform an annual bus inspection. To carry out a wheel-off inspection, it would require at least an average of 1.5 h per bus. The hourly rate ranges between $38.0[1] - 42.0[2] per hour for a heavy vehicle mechanic. The cost for a licenced vehicle tested would be $40 per hour.

- Further, to accommodate the additional task of performing wheel-off annual inspections for buses state wide, more inspectors would need to be recruited and employed. It is estimated that the workforce would have to double or triple in order to ensure that buses are inspected by their scheduled date.
- Were it to be conducted by inspectors, specialized training (e.g. the following qualifications AURHTJ003 - Remove, inspect and refit heavy vehicle wheel and tyre assemblies (Release 1), AURTTB007 - Remove and replace brake assemblies (Release 1)) would be required for LVTs performing wheel removal and refitting, the practice of which was also introduced in Ontario, Canada to reduce wheel separation for commercial vehicles (Ministry of Transportation, 2009).
- As a typical bus tyre weighs between 70 – 90 kg, which is quite heavy, there are potential occupational health and safety issues (e.g. higher risk of back injury) for inspectors, who would be removing and refitting wheels during inspections at high frequency (source: communication with practitioners in the field).
- Existing inspection stations would need to be upgraded (equipped with a pit or hoists) and workplace layout modified to provide an adequate work environment, as current inspection stations are not equipped to conduct wheel disassembly, assembly, and road test. In addition, as the capacity of inspection stations decrease due to the extra time required for each inspection, additional inspection bays would be required to maintain an appropriate schedule. The upgrade and expansion (relocation if expansion is not possible) would apply to all inspection sites, including mobile sites. According to the international standards for the design and construction procedure, it would take a substantial amount of time and incur significant capital expenditure (American Public Transportation Association, 2011; Anderson, Molenaar, & Schexnayder, 2015).
- In view of the procedure for wheel disassembly, brake inspection and wheel assembly, the procurement of the following tools would be essential: jacks, stands, impact gun, lever, wheel hoist trolley, torque wrench (SCANIA, 2006) and etc.

4.2.3 Operational and capital costs for operators

In terms of the costs at the operators' end, the following were identified.

- Revenues would be lost with buses being off the road for additional time, at $150.00 per hour[3].
- For operators that have RSI coming to their depots for annuals inspection, the additional time required per inspection would mean service bays being occupied for longer periods, reducing operators' capacity to carry out their normal day to day preventative service and maintenance, and the need for more service bays.

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[1] talent.com
[2] Seek.com
[3] Quoted from Dyson

A summary of potential costs is provided in Table 4-1.

Table 4-1 Costs associated with the wheel disassembly procedure

	Category	Items	Predicted
At inspectors	Labour costs	Average time for annual inspection	At least an extra 1.5 h per bus
		Recruitment and employment of extra inspectors	Double of the current workforce
		Training required to conduct wheel removal and refitting	Unknown
		Potential OHS issues for inspectors	Unknown
	Capital expenditure	Upgrade of inspection bays and modification and expansion of current workplace layout at inspection stations	Unknown
		Tools including the following: jacks, stands, impact gun, lever, wheel hoist trolley, torque wrench	Unknown
At operators	Operational costs	Service time (vehicle) taken out of operator per inspection	At least an extra 1.5 h per bus
	Capital costs	Additional investment on service bays	Unknown

5 Discussion and Recommendations

The findings of the desk-top review, data assessment and site visits suggest that there are few potential benefits of mandating wheel disassembly to assess brakes during annual inspections of buses in Victoria. There were no demonstrable benefits of the initiative regarding service reliability, vehicle improvements, or operational factors. It was also noted that any safety-related benefits or risks were difficult to quantify. In contrast, the evidence suggests that there are substantial costs for bus inspectors such as capital investment, increased labour costs, for bus operators such as revenue loss, capital investment, and potential long-term vehicle and safety risks (although these require quantifying). All these new costs would place considerable inflationary pressure on the price paid for a bus inspection by the operator, as well as the State Government, given that the operator recovers its cost through the service contract.

Overall, it is suggested that a decision-making approach be adopted for wheel disassembly during brake inspections. This is illustrated in Figure 5-1, a flow-chart of decision-making options.

First, as the initiative requires substantial capital investment, is time consuming and labour intensive, it is recommended that the DO clarify the motives for dismantling wheels and taking photos. It is noted that:

- The claim of using photos as surveillance to urge inspectors to do their jobs properly has no proper clause.

- The reasoning of being consistent with the inspection practices of other vehicles (private vehicles) and streamlining online reporting system does not promise of any practical benefits. Instead, evidence of the safety impacts of such practices in the private vehicle sector should be gathered and would be more convincing.

It is also recommended that, to validate the motive of achieving safety benefits, VicRoads should consider establishing a more comprehensive understanding of the prevalence of brake defects and gather solid evidence on the contributing factors to bus brake defects among inspections, in-depth incident investigations, etc. Upon establishing an understanding of the contributing factors, verification of whether these defects can be detected and rectified by wheel disassembly should be established.

Furthermore, the procedure to examine following wheel disassembly (e.g. measuring friction material thickness, rotor and drum dimensions etc.) and profiles of the 14 photos should be specified in greater detail to acquire and analyse quantitative (measurements) and imagery (photos) information in order to to gain a more in-depth understanding of the bus fleet and achieve the intended benefits.

Regarding the findings of the cost benefit assessment, it is recommended that the following options could be considered for comparison.

The null option (Option 0) is to keep the current inspection procedure, which aligns with international best practice.

Option 1 is full wheel disassembly for all vehicles. If it is decided that dismantling wheels is the only way to guarantee brake and wheel integrity, VicRoads should consider establishing a more specific and instructive DO on the aspects to examine. For instance, devising a corresponding inspection procedure and checklist to make sure the critical components are inspected and recorded for compliance and rectification, which also needs to be specific with disc (e.g. measure rotor and pad friction material thickness) and drum brakes (e.g. measuring brake shoe lining thickness and drum diameter). Without a clear, structured and detailed plan, the practice is likely to be costly, inefficient and with minimum benefits.

An alternative to full wheel disassembly is conditional wheel disassembly (Option 2). Four variations are listed as follow.

(a) Disassemble wheel on rear brakes only. According to the inspection and incident records of Victorian buses, rear wheels are more susceptible to defects.

(b) Wheels are only removed at inspection time if the bus fails its brake roller test. The rationale of this variation is that there is a strong relationship between the brake performance as measured in roller brake tests and that on the road, as stated by National Heavy Vehicle Regulator (2017) and it is consistent with industry expertise.

(c) Disassemble wheels if there is physical evidence of a defect, fluid leaks, irregular brake shoe or pad wear." (c) is consistent with the practice in some jurisdictions. A protocol and comprehensive checklist of signs should be developed, based on which, inspectors can infer the brake integrity and decide on whether wheel disassembly is warranted or not. There has been some progress (practices in other jurisdictions and expertise from stakeholders) on the checklist of signs for proceeding with wheel dismantlement.

(d) Another variation is to target operators and buses with subpar brake performance (based on inspection and incident records). Indeed, in addition to the compliance activities at regular spots noted previously, TSV has conducted a number of targeted audits at depots of concern, which were efficient and effective.

Although wheel disassembly provides full access to and in-depth details of the mechanical components of the brakes, it comes at a potentially substantial cost, both monetary and safety (the potential risk of jeopardizing brake and wheel integrity, which may contribute to incidents). Non-destructive tests can be a viable option to consider before going down the road of wheel disassembly. Therefore, another alternative is to introduce surrogate techniques which are non-destructive (Option 3). These may include:

- Brake pad wear sensors on disc brakes enable the monitor of some critical performance indicators; and/or
- Great progress has been made in railroad and aircraft industry to monitor the condition (e.g. cracks, wheel diameter) of wheels and brakes using non-destructive tests, which have higher efficiency and lower maintenance costs.

After estimating and comparing the cost benefit ratios of the options above, VicRoads may be in a position to make a more informed decision regarding potential changes to inspection procedures.

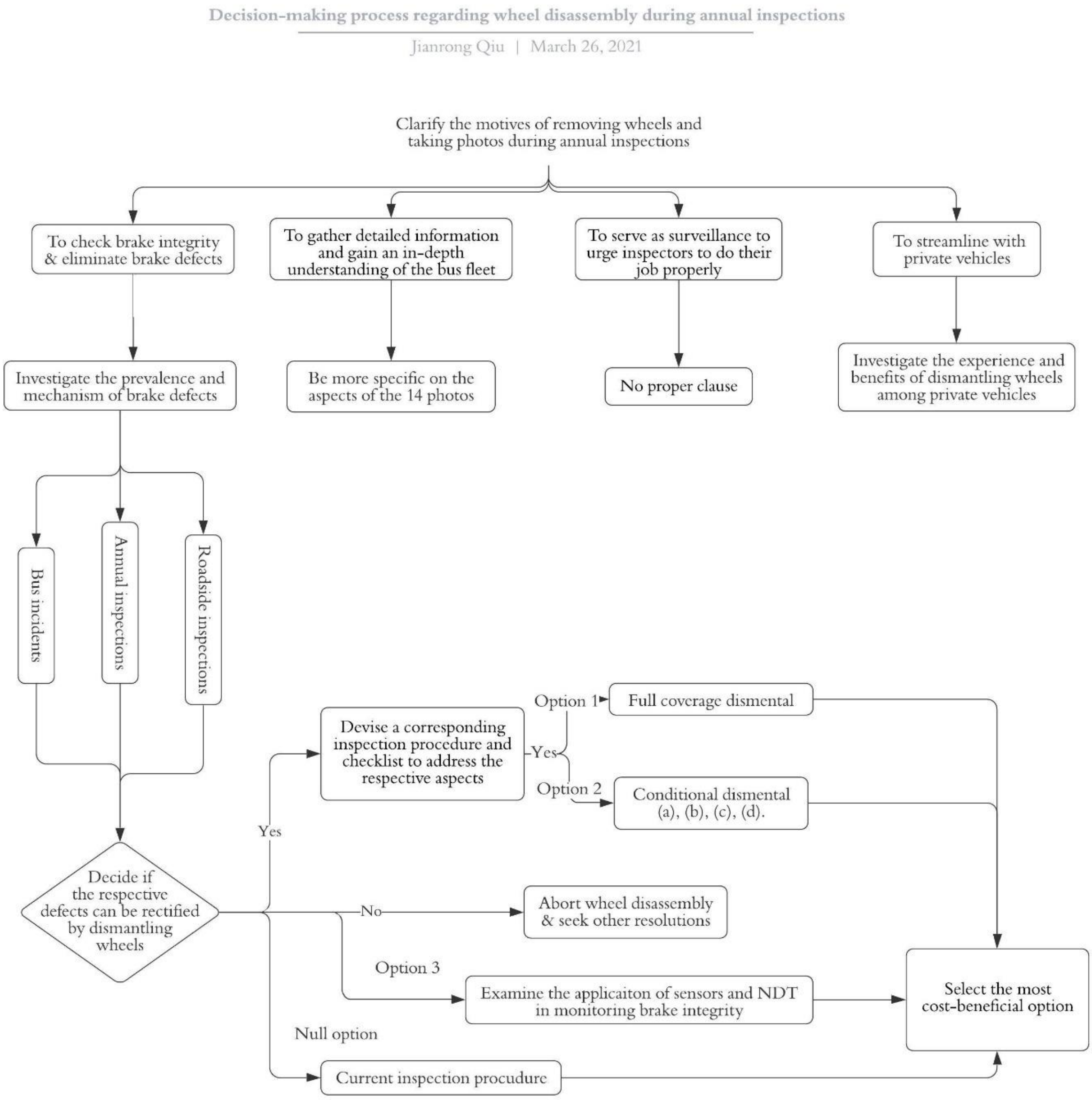

Figure 5-1 Decision-making process for wheel disassembly

6 Conclusions

This report started with benchmarking domestic and international practices in bus brake inspection and found that best-practice favors wheels-on inspection compared with wheels-off inspection. Canada, where the brake-related defects continued to account for around half of all out-of-service violations and represented the single most prevalent OOS violation across 2008 - 2014, was the only jurisdiction that introduced wheel disassembly. It is speculated that Canada initiated the procedure in response to a long-term issue with brake-related defects and attempts to improve the brake condition. However, the introduction of wheel disassembly did not appear to improve the brake condition, at least not to a significant extent.

Building on the experience in Canada, an understanding of the magnitude and nature of brake defects among Victorian buses was established by reviewing the common brake defects contributing to bus incidents and inspection failures in Victoria. Compared with a neighboring jurisdiction, the magnitude of brake defects within the Victorian bus fleet was minor. Regarding the nature of defects, the contributing factors could not be determined due to the lack of in-depth information. Furthermore, it was difficult to determine whether incidents and inspection failures could be addressed by wheel disassembly. Therefore, the benefits of the initiative are uncertain. However, the cost is estimated to be substantial based on the inference from the wheel disassembly and assembly procedure during bus periodic safety inspections at bus depots.

In view of the considerable costs versus uncertain benefits of the full wheel disassembly initiative, synthesizing the expertise from practitioners in the field, patterns from inspection and incident records and practices and techniques in other jurisdictions and transport modes, some recommendations for VicRoads to consider were made, including a decision-making framework for assessing these alternatives. It is hoped that the proposed framework will facilitate a more informed decision-making process and enhance the brake safety of Victorian bus fleet in a more efficient manner.

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8 Appendices

A1. Vehicle category in ADR

Vehicle category (Australian Design Rules 35/06 – Commercial Vehicle Brake Systems (Urban Infrastructure and Cities, 2018))

Table 8-1 Vehicle category in ADR

Vehicle Category	ADR Category Code	UNECE Category Code	Manufactured on or After
Passenger car	MA	M1	not applicable
Forward-control passenger vehicle	MB	M1	1 July 2019**
Light omnibus	MD	M2	
up to 3.5 tonnes *'GVM'* and up to 12 seats	MD1		1 November 2020**
up to 3.5 tonnes *'GVM'* and more than 12 seats	MD2		1 November 2020**
over 3.5 tonnes and up to 4.5 tonnes *'GVM'*	MD3		1 November 2020**
over 4.5 tonnes and up to 5 tonnes *'GVM'*	MD4		1 November 2020**
Heavy omnibus	ME	M3	1 November 2020**

A2. Vehicle category align with the National Heavy Vehicle Regulator

As stated by Bus Safety Victoria, the categories for bus inspections were adjusted from 1 July 2020 to align with the National Heavy Vehicle Regulator for heavy vehicle inspections.

The Large Bus category was replaced by Heavy Bus. Heavy Bus (HB) applies to all vehicles of a weight over 4.5 tonnes gross vehicle mass (GVM) with ten seats or more (including the driver). Inspection of HBs must conform to all applicable standards, design rules and national laws for heavy vehicles, including the National Heavy Vehicle Inspection Manual (NHVIM).

The Small Bus category was replaced by Light Bus. Light Bus (LB) applies to all vehicles of a weight up to and including 4.5 tonnes GVM with ten seats or more (including the driver). Inspection of LBs must conform to all applicable standards and design rules for light vehicles, including VSI26.

B. Summary of brake inspection items

Examining the criteria specified for brake inspection, an emphasis has been laid on brake drum/disk and lining/pad thickness (Table 8-2) as sufficient friction material and pad thickness ensure brake efficiency and prevent brake failure.

Table 8-2 Benchmarking of the specifications on brake measurements during inspections

Jurisdiction	Item	Method	Reasons for failure	Categories
Europe	Brake linings and pads	Visual inspection	(a) Lining or pad excessively worn (minimum mark reached).	Major
			(b) Lining or pad excessively worn (minimum mark not visible).	Dangerous
			(c) Lining or pad contaminated (oil, grease etc.).	Major
			(d) (braking performance affected).	Dangerous
			(e) Lining or pad missing or wrongly mounted.	Dangerous
	Brake drums, brake discs	Visual inspection	(a) Drum or disc worn	Major
			(b) Drum or disc excessively worn, excessively scored, cracked, insecure or fractured.	Dangerous
			(c) Drum or disc contaminated (oil, grease, etc.)	Major
			(d) Drum or disc contaminated (braking performance affected)	Dangerous
			(e) Drum or disc missing	Dangerous
			(f) Back plate insecure	Major
UK	Disc & drum		A brake disc or drum excessively worn	Major
			A brake back plate, disc or drum in such a condition that it is seriously weakened or insecure.	Dangerous
	Brake lining or pad		A brake, lining or pad less than 1.5mm thick at any point.	Major
			A brake, lining or pad, missing, incorrectly fitted, insecure or with the lining/pad no longer visible.	Dangerous
	Contamination		A brake drum, disc, lining or pad contaminated by oil or grease.	Major
			A brake drum, disc, lining or pad contaminated by oil or grease with the brake performance obviously affected.	Dangerous
			A brake back plate or calliper securing bolt loose or missing.	Major
			Restricted movement of a brake component.	Major

Canada	Brake shoe lining thickness		Bonded brake shoe lining thickness less than 2mm at any point;	Reject
			Bolted or reverted brake shoe lining thickness less than 3 mm at any point	Reject
	Drum diameter		For nominal drum size of 350 mm or less: 2.3 mm more than original drum diameter	Reject
			For nominal drum size greater than 350 mm: 3.0 mm more than original drum diameter	Reject
	Rotor thickness		Less than 39.0 mm or the minimum indicated on the brake rotor by OEM standard or industry standard	Reject
	Brake pad lining thickness		Pad thickness is less than manufacture specification or industry standard	Reject
			Bonded friction material thickness less than 3 mm;	Reject
			Reverted friction material thickness less than 5 mm	Reject
			Difference between inboard and outboard friction material thickness is greater than OEM standard or industry standard, or if limit is not available: difference is greater than 3 mm	Reject
US	Brake Drums or Rotors		With any external crack or cracks that open upon brake application.	Reject
			Any portion of the drum or rotor missing or in danger of falling away.	Reject
	Brake linings or pads		Lining or pad is not firmly attached to the shoe;	Reject
			Saturated with oil, grease, or brake fluid;	Reject
			Lining with a thickness less than 1⁄4 inch (6.35mm) at the shoe centre for drum brakes, less than 1⁄8 (3.18 mm) inch for air disc brakes, and 1⁄16 (1.59 mm) inch or less at the shoe centre for hydraulic and electric drum brakes.	Reject
			Missing or broken mechanical components including: shoes, lining, pads, springs, anchor pins, spiders, cam rollers, push-rods, and air chamber mounting bolts.	Reject
			Loose brake components including air chambers, spiders, and cam shaft support brackets	Reject

National Heavy Vehicle Inspection Manual	Disc & drum		Brake drums or discs are not fitted or have missing pieces, or cracks other than short heat cracks inside the drums or in the disc	Reject
			Drums or discs are worn beyond manufacturer's specifications	Reject
			Brake pad or shoe material does not come in full contact with brake disc or drum friction surface, excluding any crowning. *Brake pad or shoe material should not protrude from the drum by more than 3mm.*	Reject
	Brake lining or pad		Brake linings or pads are missing, broken or loose on their shoes or plates	Reject
			The thickness of the linings or pads is less than the manufacturer's recommended minimum. If this is not known or is no longer appropriate, the thickness of the linings or pads is less than the following: the rivet or bolt head on riveted or bolted linings or within 3mm of the friction material mounting surface on bonded pads or linings.	Reject
			Friction material of the linings or pads are contaminated with oil, grease, brake fluid or another substance that will reduce the friction coefficient of the friction material	Reject
			Brake chambers (including chamber clamps) or camshaft support brackets are loose, bent, cracked or missing	Reject
			Brake components such as springs, anchor pins, cam rollers or bushes, pull or push rods, clevis pins, retainers or brake chamber mounting bolts are missing, loose, damaged or broken.	Reject
			Any calliper, wheel cylinder or master cylinder leaks	Reject

C. Summary Statistics of Canadian Annual International Road check

Table 8-3 Statistics of Canadian Annual International Road check

Year	Bus inspected	Bus OOS	Bus OOS rate	Truck inspected	Truck OOS	Truck OOS rate	Combined OOS rate
2007	175	25	14.3%	7100	1324	18.6%	18.5%
2008	224	49	21.9%	7127	1289	18.1%	18.2%
2009	267	36	13.5%	7533	1353	18.0%	17.8%
2010	246	29	11.8%	7065	1434	20.3%	20.0%
2011	244	30	12.3%	7590	1431	18.9%	18.6%
2012	196	23	11.7%	6929	1262	18.2%	18.0%
2013	217	24	11.1%	7311	1597	21.8%	21.5%
2014	154	20	13.0%	8194	1827	22.3%	22.1%
2015	207	19	9.2%	8029	1511	18.8%	18.6%
2016	230	24	10.4%	7887	1480	18.8%	18.5%
2017	265	20	7.5%	7483	1475	19.7%	19.3%

Sources: (Canadian Council of Motor Transport Administrators, 2007, 2009, 2012, 2013b, 2014a, 2015, 2016, 2017, 2008, 2010, 2011)

D. Summary of bus brake incidents in NSW, 2020

The table below is a brief summary of bus brake incidents in NSW, 2020 (The Office of Transport Safety Investigations, 2020).

Table 8-4 Summary of bus brake incidents in NSW, 2020

Month	Make year	Likely fire source	Severity
Feb	2000	Faulty NSF brake calliper.	Minor
Mar	2016	Faulty NSF brake calliper.	Smoke
Dec	2007	Faulty NSF brake calliper.	Smoke
Dec	2015	Faulty NSF brake calliper.	Minor
Feb	1997	Faulty NSR brake calliper.	Minor
Apr	2019	Faulty OSR brake calliper.	Minor
Jul	2001	Faulty NSR brake calliper.	Nil
Aug	2016	Faulty NSR brake calliper.	Minor
Sep	2017	Faulty brake calliper.	Nil
Mar	2010	Sticking callipers cause rear brakes to drag.	Nil
May	2007	Faulty brake calliper adjustment mechanism.	Smoke
May	2011	Incorrectly adjusted NSR brakes.	Smoke
Jun	2013	Incorrectly adjusted NSR brakes.	Minor
May	2009	Rear brakes dragging.	Smoke
Jul	1999	Rear brakes dragging.	Smoke
Oct	2020	Rear brakes dragging.	Smoke
Oct	2008	Rear brakes dragging.	Smoke
Oct	2010	Rear brakes dragging.	Minor
Nov	2001	Brakes dragging.	Smoke
Nov	2008	Brakes dragging.	Smoke
Nov	2010	Brakes dragging.	Smoke
Nov	2006	Brakes dragging.	Smoke
Dec	2004	Brakes dragging.	Smoke
Dec	2015	Brakes dragging.	Smoke
Dec	2002	OSR brakes dragging.	Smoke
Aug	1996	Dragging OSF brakes.	Smoke
Aug	2015	Dragging NSR brakes.	Smoke
Sep	2011	Dragging OS centre brakes.	Smoke
Apr	2011	Faulty rear brake QR valve causing brakes to drag.	Smoke
Feb	2010	Ruptured parking brake airline causing brakes to drag.	Smoke

Jun	2010	Faulty park brake valve causing rear brakes to drag.	Smoke
Aug	2016	Faulty park brake valve causing brakes to drag.	Smoke
Aug	2011	Faulty park brake valve causing brakes to drag.	Nil
Aug	2012	Faulty park brake valve causing brakes to drag.	Minor
Apr	2013	Faulty EBS module causing OSR brakes to drag.	Minor
Aug	1999	Faulty OSR brake booster.	Smoke
Sep	2014	Faulty OSR brake booster.	Smoke
Oct	20018	Faulty NSR brake booster.	Minor
Aug	2012	Faulty rear brake boosters.	Smoke
Aug	1996	Faulty rear brake boosters.	Smoke
Sep	1999	Brake “S” cam over centre.	Smoke
Jan	2010	Centre axle brakes locked on.	Smoke
Feb	2011	Excessive brake heat due to malfunctioning transmission retarder.	Nil

E. RSI checklist

DATE .... INSP: ....REG NO: .... ODOM/HUB ....

OWNER DETAILS: ....

REGION: METRO .... INSP. SITE: ....SEATS: .... CC: ....

VIN:

MAKE: .... YEAR: .... LICENSE NO: ....

ENG NO: .... CERT NO: ....

NOTES: ....

....

Job No:	
Service Brake:	

ELECTRICAL

( ) Headlamps
( ) Park Lamps
( ) Clearance F-R
( ) Turn Indicator F-R
( ) Rear Lights
( ) Step Lights
( ) Interior Lights
( ) Reflectors Hazard Lights
( ) Dash Lights
( ) Screen Wipe/Wash
( ) Demister
( ) Instrument
( ) Horn
( ) Cabling
( ) Batteries

SUSPENSION

( ) Air Bag F-R
( ) Spring Shackles F-R
( ) Spring Hangers F-R
( ) Shock Absorbers F-R
( ) U Bolts F-R
( ) Stabliser Bar/Joints F-R
( ) Radius Rods/Bushes F-R
( ) Suspension Arm Pivots
( ) Chassis Members
( ) Trailing Arms

TRANSMISSION

( ) Clutch Adjust/Linkage
( ) Gear Shift
( ) Fluid Leaks Ge-Di-Ax
( ) Centre Bearing F-M-R
( ) Slip Joint
( ) Tailshaft Loops
( ) Axle Nuts
( ) Mountings
( ) Neutral Safety Switch
( ) Clutch pedal pad

STEERING

( ) Box Adjust Wear
( ) Column
( ) Wheel
( ) Linkage Joints
( ) Power Systems
( ) King Pins/Ball Joints
( ) Alignments
( ) Damper
( ) Lock Stops

BRAKES/SERVICE

( ) Adjust
( ) Worn Linings
( ) Pedal Feel
( ) Fluid Level/Leaks
( ) Slack Adjusters
( ) Lines/Hoses
( ) Air/Vac Leaks
( ) Air/Vac Warning
( ) Air/Vac Build up
( ) Pedal Pad

BRAKE TESTS

( ) Test Front N/S
( ) Test Front O/S
( ) Test Rear N/S
( ) Tag N/S
( ) Tag O/S
( ) Park Brake N/S
( ) Park Brake O/S

BRAKES/OTHER

( ) Adjust
( ) Linkage
( ) Spring Brake
( ) Warning
( ) Exhaust Brake

ENGINE

( ) Noise
( ) Fumes
( ) Mountings
( ) Oil Leaks
( ) Cooling System
( ) Exhaust System
( ) Belt Drives
( ) Fuel System
( ) Fuel Tank
( ) Emission Control
( ) Eng. Cover/Seal/Insul

TYRE/WHEELS

( ) Front N/S
( ) Front O/S
( ) Rear N/S
( ) Rear O/S
( ) Tag N/S
( ) Tag O/S
( ) Spare
( ) Inflation
( ) Studs

BODY

( ) Bumper Bars
( ) Exterior Panels
( ) Paint Work
( ) Regulation Signs
( ) School Bus Signs
( ) Destination Sign
( ) Number Plates
( ) Rear Marker Pla
( ) Body Mountings
( ) Body Framing
( ) Boot & Bins
( ) Glazing
( ) Window Operati
( ) Emergency Exits
( ) Door Operation-Seal/in
( ) Springs F-R
( ) Flooring
( ) Interior Trim/Uphol
( ) Seat Belts
( ) Door Interlock
( ) Sensitive Edge
( ) Steps
( ) Hand Rails
( ) Luggage Racks
( ) Seat Frames
( ) Seat Mounting/Spacing
( ) Ventilation

ACCESSSORIES

( ) Fire Extinguisher
( ) Rear Vision Mirror
( ) Speedometer

F An anatomy of a bus incident

A routine vehicle brake pad replacement, it was found that the mechanic responsible for the repair did not tension the rotor bolts to the correct tension. Whilst the vehicle was being driven it was established that there was a fault in this area and upon inspection it was established that 2 x bolts were missing and brake calliper was loose.