Office of Transport Safety Investigations

BUS SAFETY INVESTIGATION REPORT

BUS FIRE

SYDNEY HARBOUR BRIDGE

MILSONS POINT

15 SEPTEMBER 2016

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THE OFFICE OF TRANSPORT SAFETY INVESTIGATIONS

The Office of Transport Safety Investigations (OTSI) is an independent NSW agency whose purpose is to improve transport safety through the investigation of incidents and accidents in the rail, bus and ferry industries. OTSI investigations are independent of regulatory, operator or other external entities.

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

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EXECUTIVE SUMMARY

During the afternoon peak period on Thursday 15 September 2016, a State Transit Authority (STA) bus, MO3726, caught fire on the Sydney Harbour Bridge at Milsons Point. At the time, the bus was travelling northbound with 22 passengers and a driver on board. The driver noticed smoke and flames coming from the exterior rear of the bus as it approached the north-western bridge pylon.

The driver stopped the bus in lane 2 and passengers evacuated onto the road in lane 1. The driver and two passengers suffered from smoke inhalation and were transported by ambulance to hospital where they were treated and released later that evening.

The investigation found that the fire started due to an electrical malfunction in the engine bay at the rear of the bus. The fire intensified, consuming flammable materials in the engine bay and eventually spread into the passenger saloon. The back half of the bus suffered substantial damage.

It is likely that the fire was initiated by a short circuit of the auxiliary alternator cables where they crossed the edge of the near side rear chassis rail. The main battery switch was left in the 'on' position after the driver shut the engine down and evacuated the bus. This meant that there was an ongoing supply of battery power to the source of the fire in the engine bay. This may have caused the fire to intensify due to the continuous supply of thermal energy. The bus was not fitted with an engine bay fire suppression system. The suppression system was scheduled to be installed in the month following the fire.

It was recommended that all buses be fitted with suppression systems, that the bus shutdown process be simplified, and that a review of the design and placement of electrical cabling on buses be undertaken to reduce the likelihood of short circuit events occurring. Other recommendations were made in respect to training of bus drivers and maintenance personnel.

Further recommendations were made to bus regulators to increase monitoring of operator maintenance procedures and strengthen bus industry standards.

Full details of the Findings and Recommendations of this bus safety investigation are contained in Parts 3 and 4 respectively.

PART 1 FACTUAL INFORMATION

Events leading up to the occurrence

1.1 On the morning of 15 September 2016 a bus driver started a shift at the State Transit Authority (STA) Willoughby bus depot. The driver had arrived at work around 0700[1] and signed on at 0731. The driver was rostered to work a morning shift and an afternoon shift. The morning and afternoon split shift, accompanied with a long lunch break, is a common arrangement in the bus industry and allows bus operators to cater for peak passenger times.

1.2 The driver was allocated a bus for the morning shift and, after inspecting the bus, left the depot at 0741. The driver completed two separate bus routes around North Sydney and returned to the depot after 0900. Upon returning to the depot the driver carried out assigned yard duties. The driver finished yard duties at 1140 and then had lunch in the depot.

1.3 The driver's afternoon shift commenced at 1430. The driver assisted the yard supervisor with moving buses from the maintenance area into the yard. One of the buses in the maintenance area was MO3726. This was the bus allocated to the driver for the afternoon shift. The bus had been in operation from 0716 that morning and had travelled 44 km. Before taking the bus from the maintenance area the driver checked the computer maintenance record to see if the bus had any outstanding defects. The bus had no defects marked against it and the driver drove it into the yard and parked the bus.

1.4 Before starting a shift, drivers are allocated 5 minutes to conduct a visual check for defects. The driver conducted a visual inspection of the bus. This consisted of walking around the bus, entering the bus by the back door and walking up the aisle. After activating the electronic ticketing system on the bus the driver departed the depot at 1506.

1.5 The first afternoon trip was a school route which commenced at North Sydney Boys High School. Once the students embarked, the driver departed close to

[1] Times in this report are in 24-hour clock form in Australian Eastern Standard Time.

schedule at 1519. The students were dropped off at various stops and the driver completed the route near St Leonards' station.

1.6 The driver then drove south across the Sydney Harbour Bridge into the CBD without any passengers on board. The bus was scheduled to depart Loftus Street near the corner of Bridge Street at 1545. Before starting this trip the driver stopped at Wynyard, parked the bus and had a short coffee break.

1.7 The bus arrived 6 minutes late at Loftus Street. Passengers boarded the bus and the bus departed at 1552. The driver drove north across the Sydney Harbour Bridge, dropped off the last passenger at Roseville and completed the trip at East Lindfield at 1624, one minute behind schedule. The driver returned to the CBD to commence the final trip for the day. The bus arrived at 1649 in Gresham Street, the driver parked and secured the bus and went to a nearby food court for a rest stop. The driver returned to the bus and departed Gresham Street at 1708. Due to traffic congestion it took five minutes to travel the short distance around the block to Loftus St.

1.8 Route 204 is a city to Northbridge service, running during Monday to Friday peak hours. The afternoon service picks up passengers at two CBD stops, crosses the Sydney Harbour Bridge, bypasses North Sydney, stops first at Cammeray and then all stops to Northbridge. It was scheduled to depart Loftus Street at 17:09 and arrive at Northbridge at 1734.

1.9 At 1713, the bus arrived at Loftus Street, the doors opened and passengers commenced boarding. Seven passengers boarded the bus. The bus departed Loftus Street at 1714 and turned left into Bridge Street. At 1717 the bus stopped on Bridge Street and a further 15 passengers boarded the bus, bringing the total number of passengers to 22.

1.10 At 1718 the bus departed Bridge Street, five minutes behind schedule. The route took the bus west up Bridge Street, onto Grosvenor Street, across York Street onto the Bradfield Highway and the Sydney Harbour Bridge deck (see *Figure 1)*. At 1720:49 the bus passed underneath the toll gantry at the southern entrance to the bridge. The driver said there was no performance issue with the bus. CCTV footage from a bus travelling behind MO3726 showed no external sign of smoke or fire. The traffic at the time was flowing freely with vehicles in all lanes. The bus was travelling at approximately 60 km/h and below the variable speed limit posted on the overhead gantry of 70km/h.

Source: Sydways

Figure 1: Map of incident location and route of bus

The occurrence

1.11 The bus travelled northbound over the bridge in lane 3 and, about half way across the bridge, the driver checked the near-side mirror and changed to lane 2. About six seconds later, at 1722:03, CCTV footage showed a bright orange flash at the rear of the bus. The driver checked the driver's-side mirror and then the centre mirror and realised that the bus was on fire. The driver reported seeing *"liquid – liquid sparks ... then checked the dash to see if the fire alarm had come on"*. The fire alarm had not activated.

1.12 At 1722:06 smoke started to enter the passenger compartment from the rear near-side corner of the bus. About four seconds later a passenger, seated at the rear of the bus, turned to look at the smoke and at the same time the driver started to call out to warn the passengers. The passengers started to leave their seats and move towards the doors. By this time the bus had just passed the north-western pylon at Milsons Point.

1.13 The driver was worried about what kind of fire it was and decided to stop the bus as soon as possible. As the driver slowed the bus, it was apparent that the fire had started to flare up. The driver slowed the bus gradually so that no one would fall over. At 1722:28, the driver stopped the bus about 70 m past the north-western pylon in lane 2. The driver selected neutral gear, applied the handbrake, turned off the ignition. The main battery switch remained on.

1.14 The driver said the fire alarm activated as the passengers were evacuating. The passengers disembarked from the bus using both the rear and front double doors. They all stepped off the bus into lane 1. Ten passengers left by the rear door while another 12 passengers and the driver disembarked by the front door. Due to the smoke coming from the rear the driver could not see the traffic behind the bus. The driver was worried about passengers being struck by traffic as they stepped off the bus into a live traffic lane. The overhead gantry lane markings were still displaying a green arrow for lanes 1 to 4 (see *Figure 2*).

Source: State Transit Authority – CCTV forward facing camera on MO 1386

Figure 2: Bus on bridge shortly after stopping, looking north

Events following the occurrence

1.15 As the passengers disembarked, the driver activated the floor mounted emergency alarm by foot, which in turn connected the bus' communication radio to the Transport Management Centre (TMC). This gave the driver 30 seconds of unbroken one-way communication to inform the TMC of an emergency. The driver called out: "FIRE, FIRE, FIRE" twice. The driver was the second last to evacuate. The time was 1722:38. The driver immediately stepped back onto the bus to retrieve the keys from the ignition and again checked that the handbrake was applied. Smoke was rapidly filling the bus.

1.16 The driver left the bus for a second time and went to the front of the bus. Standing in lane 3 the driver tried to wave down another STA bus (see *Figure 3*). The other bus initially stopped but then kept going. Traffic was still coming past in lane 4. The driver was not wearing a hi-visibility safety vest and it was left behind on the back of the driver's seat. The driver then went to the open driver's window and reached into the bus in an attempt to retrieve the safety vest. The vest was out of reach. The driver walked around the front of the bus then re-entered the bus at 1723:06. The driver took the safety vest from the back of the seat and left the bus for the third and final time.

Source: State Transit Authority – CCTV forward facing camera on MO 1386

Figure 3: Driver attempted to wave down another STA bus

1.17 The driver put on the safety vest and then went to the rear of the bus via lane 1. The driver assessed the situation and decided that the fire was too far advanced to use the on board fire extinguisher. An unknown person approached the driver with a small portable fire extinguisher and the driver explained that it was of no use.

1.18 The overhead gantry lane indication for lane 1 changed from a green arrow to a red cross at 1723:19. This gave drivers a warning not to travel in lane 1. The driver then walked along lane 4 as a visible warning to vehicles. The driver was standing close to a continuous stream of southbound traffic in lane 5. Soon after, the other gantry lane indicators changed to a red cross to close all northbound traffic.

1.19 The driver then walked to the front of the bus. At 1724:00, the driver looked through the front windscreen to check if any passengers were still inside. Most of the passengers had moved well away from the bus by walking northwards. Five passengers were standing in a group about 15 m ahead of the bus in lane 1. One of the passengers approached the driver and asked if a full fare would be charged having forgotten to tap off the opal card reader. The driver told this passenger to move away and not to worry about the fare. The driver was fairly certain that all passengers were off the bus but then asked the passengers if this was so.

1.20 The driver tried calling the Willoughby Depot to inform them of the situation and to check if the emergency call was received. The first call was made at 1725, but was unsuccessful. A further three call attempts were made until a successful call was made at 1729. The duty officer informed the driver that the first emergency call was successfully received by TMC.

1.21 At 1726:37, a Roads and Maritime Services (RMS) emergency response vehicle with flashing lights positioned itself about 50 m north of the bus in lane 2. The driver and passengers moved next to the emergency vehicle. Using a mobile phone, the driver then took a self-portrait photograph with the burning bus as the background. This image was posted to a Facebook account and was later broadcasted by the media.

1.22 The RMS emergency response crew attempted to extinguish the fire applying four portable fire extinguishers into the engine bay. Their attempts were unsuccessful as the bus fire reignited and continued to burn.

1.23 Fire and Rescue NSW arrived at the scene at 1730. By this stage the fire had taken hold of the rear section of the bus. The fire was extinguished by Fire and Rescue NSW at 1743 (see *Figure 4*). The NSW Police Force attended and interviewed the driver. NSW Ambulance also arrived and made an initial medical assessment of the passengers and the driver. The driver and two passengers were taken by ambulance to Royal North Shore hospital for further assessment. They were discharged at about 2200 that evening.

1.24 The bus was removed from the scene by a RMS heavy tow vehicle at 1755 and towed to the Pacific Highway at Milsons Point. This enabled lane 4 to reopen. All lanes were reopened at around 1900. At 2118 the bus was towed to the STA Leichhardt bus depot. The bus was quarantined by OTSI and examined by an OTSI investigator the following morning.

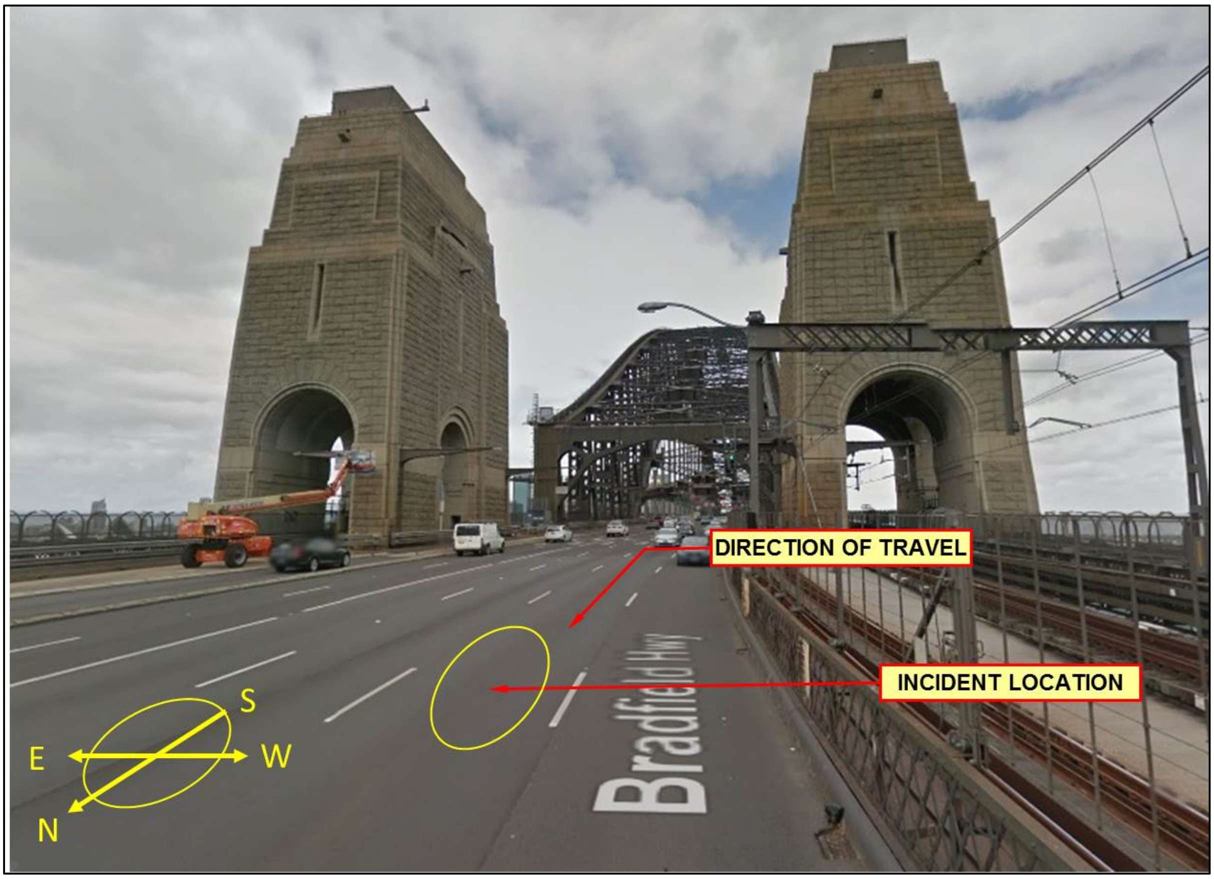
Source: Peter Mullen pmullen.com

Figure 4: Bus on bridge, fire extinguished

Incident location

1.25 The incident occurred in lane 2 of the Bradfield Highway on the Sydney Harbour Bridge at Milsons Point (see *Figure 5*). The bridge deck carries, at this point, from west to east, a bicycle lane, twin rail lines, the six-lane Bradfield Highway, a bus lane, the one-lane Cahill Expressway and a pedestrian footpath.

1.26 The driver stopped the bus about 70 m past the north-western pylon in lane 2.



Source: Google

Figure 5: Bradfield Hwy and incident location, looking south

1.27 The Bradfield Highway has a tidal flow lane system where the allocation of lane direction is dependent on traffic volume. Lane direction is controlled by the TMC. The TMC manage the road network during peak travel times, major events and unplanned incidents such as this. TMC also monitor and coordinate public transport operations.

1.28 Overhead gantries, at various points on the bridge, display the speed limit and lane direction. The incident occurred during the afternoon peak with the majority of the traffic on the bridge heading north out of the CBD. This meant lanes 1–4 were designated for northbound traffic and lanes 5–6 for southbound traffic.

Environmental conditions

1.29 The afternoon of 15 September 2016 was dry and cloudy. The Bureau of Meteorology recorded a temperature of 21°C at 1500 at the Sydney Harbour (Observatory Hill) weather station about 1.5 km south of the incident. At 1500 the wind was recorded from the west-north-west at 35 km/h. Video and photographs from the time of the incident show the smoke being blown around the bus, then predominantly towards the east. Apart from the likely effect of wind on the promotion of the fire and the dispersal of smoke, it was determined that the environmental conditions played no part in the incident.

Bus information

1.30 The bus was a two door city bus, registration MO3726, a 1996 Scania L113CRL diesel powered model (see *Figure 6*). It was fitted with an Ansair Orana body. The bus was operated by the STA out of the Willoughby Depot. There were 155 other buses of the same model in the STA fleet.

Source: OTSI

Figure 6: Similar model Scania bus

1.31 The odometer reading at the time of the incident was 879,204 km. Maintenance records indicate that the bus had a routine 6-monthly service on 22 July 2016. There were no defects detected in the engine bay area during this check. A heavy vehicle inspection was also conducted by the RMS on 9 August 2016. Again, no defects were recorded as a result of this inspection.

1.32 The bus was authorised to carry 60 passengers, 45 seated and 15 standing. At the time of the incident there were 22 passengers on board, all seated. The bus had two door openings, one next to the driver and one mid-way towards the rear. Both were on the near side[2] of the bus and both consisted of two door leafs.

1.33 There were no previous reported fire incidents for MO3726.

Driver information

1.34 The 36-year-old driver was also a qualified heavy vehicle mechanic. First authorised to drive buses in 1999 when working at the STA as an apprentice mechanic. The driver continued driving buses for other companies after leaving the STA and then re-joined the STA in 2012 as a bus operator.

1.35 The driver was familiar with the route, fully qualified and medically fit.

Related fire occurrences

1.36 At STA, this model of Scania was involved in three similar incidents. The first on 19 July 2008, when bus MO3717 had electrical wiring overheat due to the alternator wiring harness come into contact with the chassis rail. It was a minor incident which resulted in smoke and melted wiring. The second incident occurred on 20 August 2008 (MO3806), and the third on 25 October 2010 (MO3750). All three incidents were the result of electrical cables contacting or grounding to the chassis. While the failures had similar characteristics the cable types varied between alternator cables and auxiliary cables.

1.37 As a result of these three incidents STA conducted a fleet inspection of the Scania L113CRL model. STA conducted associated rectification work.

1.38 OTSI has collated and published summaries of reported bus fire incidents in NSW since 2012. Electrical faults are found to be a common initiation source for bus fires. The results have been 18(23%) in 2016, 11 (28%) in 2015, 6 (21%) in 2014, 8 (29%) in 2013 and 4 (27%) in the 2½ years to 30 June 2012.The majority of the incidents were caused by short circuits.

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[2] The left side when looking forward in the bus is the near side. The right side is the off side.

1.39 Other research[3] found that in the period 2003–2007 US fire departments responded to an average of 2400 fires involving buses, school buses, or trolley buses per year. Electrical failure or malfunction played a role in 24% of these fires.

1.40 A similar fire occurred on a bus at Ashfield in 2015. Also an STA bus, this time a 1999 Volvo B10BLE model, 24 passengers were on board and all evacuated safely. OTSI conducted an investigation into the incident and determined the cause to have been a short circuit of the cable which connected the electrical power feed from the alternators. The cable had not been adequately secured thus allowing the insulation to wear and so expose the wiring.

[3] Aherns, M. *U.S. Vehicle Fire Trends and Patterns*, National Fire Protection Association, June 2010. p. 25.

PART 2 ANALYSIS

Introduction

2.1 The investigation focussed principally on the factors that contributed to the initiation of the fire: the evacuation of passengers, emergency response, installation of bus fire suppression systems and driver training.

Damage

2.2 The bus sustained substantial damage particularly to the rear of the bus. The fire commenced in the engine bay, spread into the interior of the bus through the rear floor hatch, and then moved forward through the passenger saloon (see *Figure 7)*. The passenger seating was destroyed up to the rear door. The interior ceiling was significantly damaged throughout the bus. The bus was not completely destroyed due to the efforts of Fire and Rescue NSW.

Source: OTSI

Figure 7: Interior of the bus

2.3 The entire engine bay sustained considerable fire and heat damage (see *Figure 8)*. Many components were melted or destroyed. This included: plastic engine bay tanks, insulation on wiring, polymer coolant hoses and some metal alloy components. Some of the liquids from these tanks and hoses added to the fuel loading. These liquids included: diesel fuel, power steering fluid and air-conditioning coolant (ethylene glycol). According to the driver, the fuel tank was half full, containing approximately 120 litres of diesel. Also, a significant quantity of engine oil was released from the engine sump during the fire as the alloy sump melted.

Source: OTSI

Figure 8: Left: Rear MO3726 Right: Rear of similar model bus - MO3743

2.4 The engine turbocharger and surrounding areas were examined and, although these areas displayed considerable heat damage, it was determined to be consequential to the fire. The turbocharger was relatively new and had only been replaced on 16 August 2016. STA conducted a post-incident inspection of the turbocharger and was found it to be in serviceable condition.

Initiation and spread of fire

2.5 The fire was initiated in the engine bay at the rear of the bus. It is likely that an electrical short circuit[4] occurred in the area where the auxiliary alternator cables crossed the near side chassis rail. There was evidence of electrical arcing on the edge of the chassis rail and one of the cables was severed at the point where it crossed the rail (see *Figure 9)*.

2.6 The cables from the primary alternator also showed evidence of a short circuit. The heat effect was less in this area compared to the auxiliary alternator cables. The STA technical investigation found:

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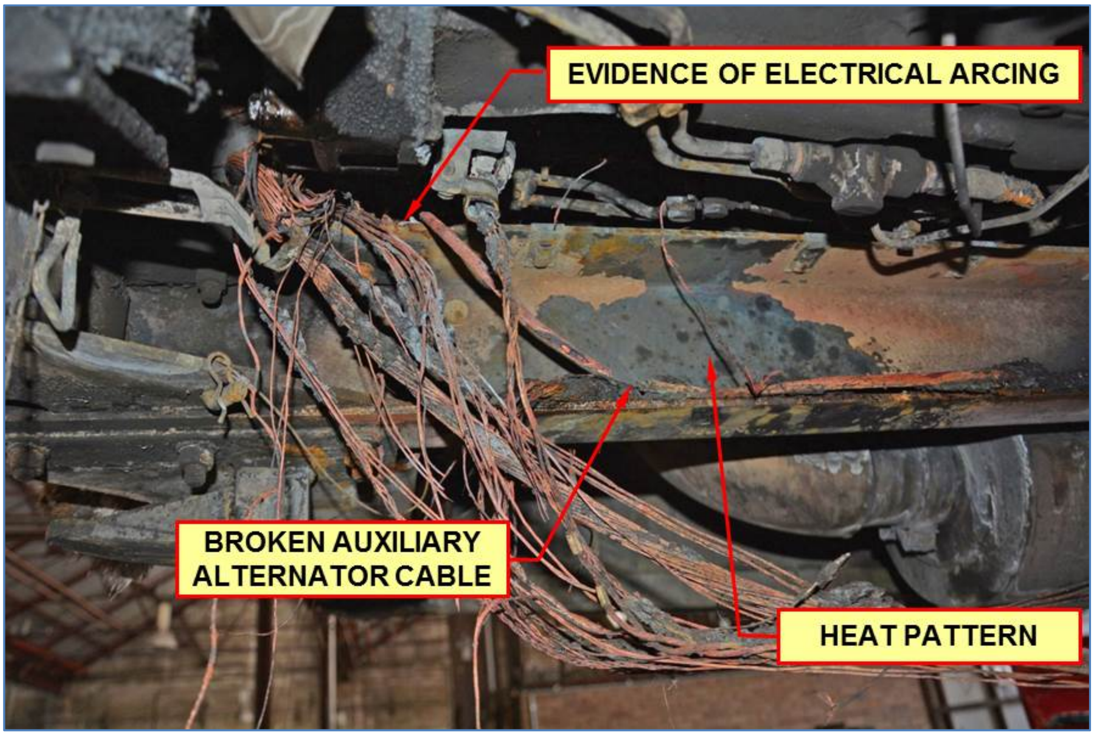
[4] 'A short circuit is when there is direct contact between a current carrying conductor and another conductor.' - Kirk's fire investigation (2012) DeHaan. J.D.; Icove.D.J., 7th Ed. p.79.

'The main B positive and B negative cables from the auxiliary alternator that connect to the main B positive terminal of the starter motor and B negative to the near side rear (NSR) main chassis rail had both been severed by a major short circuit from contacting the upper edge of the NSR chassis rail. The evidence indicates that this high amperage short circuit caused ignition of flammable materials in close proximity of this area and was the source of the fire. On inspection the auxiliary alternator was found to be seized: the damage consistent to a high level current passing through.'[5]



Source: OTSI

Figure 9: Chassis rail and cabling

2.7 The bus had a 24-volt electrical system, comprised of four 6-volt batteries, located in a compartment behind and below the driver (see *Figure 10)*. The batteries were connected in series by bridging cables. These batteries distributed power to the numerous systems required for the bus' operation. The insulation around the cables to the battery terminals had partially melted due to the electrical short circuit.

2.8 The bus was not shut down according to procedures when the driver stopped and evacuated the bus. The driver switched the engine off and took the keys from the ignition; however, the driver did not shut the battery main switch off. This meant that there was a continuous supply of power via the main cable

[5] STA Internal memo/investigation report on engine bay fire MO3726. 9 November 2016. p.3

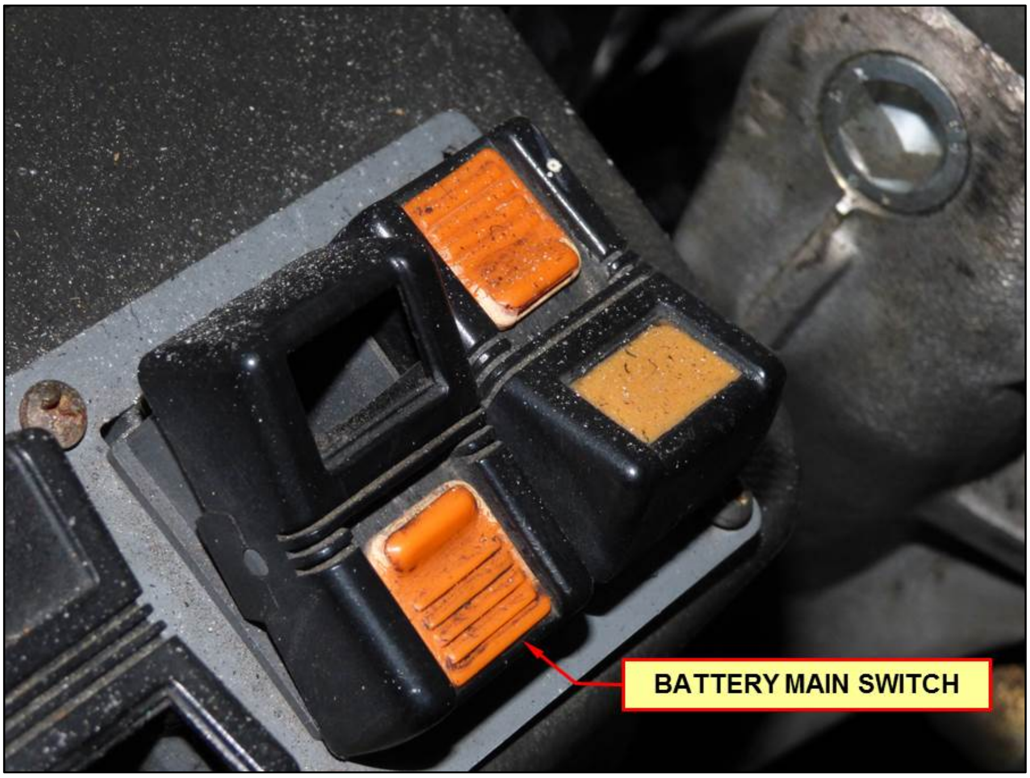
from the batteries at the front of the bus to the engine bay. This may have caused the fire to intensify due to the continuous supply of thermal energy.

Source: OTSI

Figure 10: Batteries and melted insulation on bridging cables

2.9 The battery main isolation toggle switch was located on the dashboard of the bus (see *Figure 11)*. Like many switches on the dashboard, there was no label to indicate its purpose. The switch was not equipped with a mode indicator light. The driver was familiar with the location and operation of the switch. As a trained mechanic, the driver would also be aware of the importance of switching the power off. It was likely that the driver overlooked this step in the rush to evacuate the bus.

2.10 On this model bus there was no other battery isolation switch. On some other model buses manual battery isolation switches are found in the battery compartment or in the engine compartment. The dash mounted battery isolation switch on this bus was identical in functionality to a manually operated battery isolation switch.



Source: STA

Figure 11: Battery main switch in 'on' position

2.11 Following the commencement of the fire, the fire spread throughout the engine bay consuming flammable sources. As previously mentioned, these sources included plastics from engine parts, tanks and cabling, residual oil in the engine and flammable liquids released from melted tanks and pipes.

2.12 CCTV shows that smoke started entering the passenger saloon at 1722:06 in the vicinity of the nearside rear corner (see *Figure 12*). It is possible that a heat seal failed when subjected to intense heat or flames from the engine bay. Joints are sealed to ensure that gases from the engine bay do not enter the passenger saloon during normal operation. The sealant will eventually fail if exposed to fire or intense heat.

2.13 The fire eventually entered the interior saloon of the bus at 1725:56 through the rear floor engine inspection hatch. The fire then rapidly spread forward throughout the passenger saloon.

Evacuation of bus

2.14 The evacuation of the bus occurred quickly. The passengers and driver noticed smoke coming from the rear nearside area about 4 seconds after it was first visible on the CCTV.

Source: STA CCTV on MO 3726

Figure 12: Passengers seated at rear of bus as smoke enters saloon

2.15 The passengers moved quickly from their seats when alerted by the driver. They all stood and waited by their nearest door for the bus to stop. After the bus was brought to a halt, the driver applied the handbrake, opened the doors and told the passengers to evacuate. All persons were off the bus within ten seconds (see *Figure 13*).

2.16 The driver stepped off the bus just before the last passenger stepped off the bus. About 90 seconds later the driver approached the bus and looked inside the bus through the front windscreen. Although being fairly certain that all the passengers were off, the driver said it was a final check to see if anyone was still on board.

Source: State Transit Authority – CCTV forward facing camera on MO 3726

Figure 13: Looking north: passengers evacuating from bus

2.17 With the benefit of hindsight, the driver would have been better to have stopped the bus in lane 1, partially in lane 1, or at an angle covering lane 1 and 2. This would have provided an effective barrier to prevent vehicles coming up on the inside of the bus. The visibility for other drivers was poor due to smoke and there was potential for evacuating passengers to be struck by vehicles as they stepped directly into a live traffic lane. However, ideal actions are not always possible in high workload situations and it was difficult for the driver to make perfect judgement of the situation. Research has shown that increased mental workload can impair driving performance.[6] The bus was on fire and the driver made the correct decision to evacuate the bus quickly.

2.18 The driver said that the risk of passengers being hit by traffic was considered. As the driver was travelling across the bridge and looking in the rear-view

[6] Driver distraction and inattention – Advances in research and countermeasures (2013). Regan, M.A, Lee, J.D., Victor,T.W., Vol.1. p.70.

mirror, it showed that traffic was slowing to increase their distance behind the bus and that the greater concern was that passengers would be trapped against the railway barrier fence if the bus was stopped in lane 1.

2.19 It is essential to evacuate a bus at the first sign of fire as the majority of fire injuries and deaths are caused by smoke inhalation. *'Asphyxiation by carbon monoxide or other toxic combination causes most fire deaths.'*[7] The same is true for vehicular fires. *'Smoke incapacitates occupants of a vehicle fast enough to impede their evacuation before the fire spreads and engulfs it.'*[8] In 2005, 23 passengers died in a coach fire in Wilmer, Texas. The majority of passengers died because of smoke inhalation, others died as a result of thermal injuries. Rescuers were hindered due to heavy, black smoke from the fire inside the coach. The fire overwhelmed the bus within a few minutes and prevented rescue attempts beyond the first few rows of seats.[9]

Fire extinguisher and alarms

2.20 An Australian Design Rule (ADR 58/00)[10] specifies that buses are to be equipped with a readily accessible fire extinguisher selected and located in accordance with the applicable Australian Standard.[11] Next to the driver's seat was a compliant 2.5 kg Dry Chemical Powder fire extinguisher. The attached service record indicated it was checked in June 2016. This was the only fire extinguisher on board. In coaches two extinguishers are required while in route buses such as this, only one extinguisher is required.

2.21 The driver did not consider using the fire extinguisher due to the severity and extent of the fire. Whilst examining the rear of the bus the driver was approached by a motorist who offered their vehicle's fire extinguisher. The bus driver declined this offer on the basis that it would be ineffective on such a large fire and possibly place them in danger if they approached the bus.

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[7] Kirk's fire investigation (2012) DeHaan. J.D.; Icove.D.J., 7th Ed. p.634.

[8] News from fire research (2016) Brandposten . Vol. 54. p.12.

[9] Motorcoach fire on Interstate 45 during Hurricane Rita evacuation near Wilmer, Texas September 23, 2005. NTSB Accident Report HAR-07/01. p.76.

[10] Australian Design Rule 58 *Requirements for Omnibuses Designed for Hire and Reward*

[11] Portable fire extinguishers and fire blankets – Selection and location. Australian Standard (AS) 2444—2001.

2.22 The bus was also fitted with an engine bay heat sensor. This dashboard-mounted light and audible alarm was functional and, according to the driver, activated shortly after the bus stopped.

Source: Peter Mullen pmullen.com

Figure 14: Bus on bridge, Fire and Rescue NSW extinguishing fire

Bus engine bay fire suppression systems

2.23 The installation of engine bay bus fire suppression systems were commenced by STA in 2009 where all new bus supply contracts from 2009 required the bus to be delivered with a fire suppression system installed. In 2013 STA retrofitted their Mercedes Benz 0500 CNG bus fleet with fire suppression systems.

2.24 In a bid to reduce the risk of bus fires, in 2015 the NSW State Government decided to fund, through Transport for NSW (TfNSW), the installation of engine bay fire suppression in both public and private operator buses. TfNSW also specified that all new buses are to incorporate an engine bay suppression system.

2.25 The project to fit these systems in public buses was commenced by STA on 7 December 2015 and was completed within 12 months. There were 21 different STA bus models which required modification to the specified suppression system design. STA used in-house expertise in consultation with the fire suppression manufacturer to ensure each suppression system was tailored to the different engine bay configuration.

2.26 Besides STA buses, there are about 2,170 private operator buses covered under the TfNSW metropolitan and outer metropolitan private bus operators' contract. All buses less than 23 years old have been included in the plan to fit engine bay fire suppression systems. It is proposed that all buses will be retrofitted with engine bay fire suppression systems by the end of August 2017.

2.27 This bus, MO3726, was not fitted with a fire suppression system. It was due to be fitted about a month following the incident. At the time of the incident 105 of the 2164 buses in the STA fleet were waiting the installation of engine bay fire suppression systems. Since then all of the remaining operational buses in the STA fleet were fitted with suppression systems. (For more information about fire suppression systems see Appendix 2).

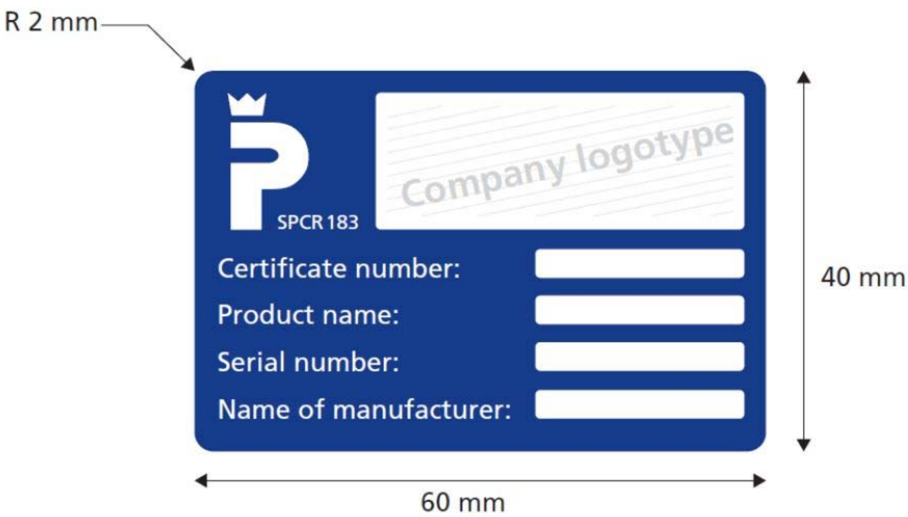
2.28 **Success of fire suppression systems.** STA notified that there were 32 activations of their fire suppression system between 2011 and the incident date in 2016. Three incidents were initiated by electrical malfunctions and had a 100% success rate in limiting the damage to a minor level. A further 16 activations occurred due to engine exhaust leaks where hot gases activated the system. This prompted a greater focus on rectifying these exhaust leaks. Lastly, there were 13 activations due to installation defects. These issues were addressed as part of the quality assurance provisions in the installation contract.

2.29 It should be noted that fire suppression systems do not constitute an absolute solution. No one system can be expected to be completely effective in all situations as there is a wide range of potential fire circumstances. However, as a large percentage of bus fires occur in the engine bay, a suppression system located in that area will reduce the risk posed by bus fires.

Fire suppression system certification

2.30 Since 2005, the Department of Fire Research at the RISE Research Institutes of Sweden (RISE)[12] has been conducting research aimed at improving bus fire safety. It has one of the largest fire research facilities in the world. Their work has culminated in the development of a standard for testing bus engine compartment fire suppression systems, namely SP Method 4912, which was introduced in 2013. The objective had been to construct a model of an engine compartment where stakeholders can evaluate the firefighting performance of different suppression systems in a well-defined and objective way.'[13]

2.31 Fire suppression systems complying with the SP Method 4912 are granted a P-Mark certificate according to SPCR 183. The P-Mark is a voluntary certification/quality mark which has a marking as shown below (see *Figure 15*).



Source: SP Technical Research Institute of Sweden

Figure 15: P-Mark symbol

2.32 The certification process was developed and is controlled by RISE Research Institutes of Sweden which rates suppression performance and limitations of fire suppression systems installed in engine compartments of buses and coaches. Certification involves confirmation by an independent third party that

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[12] Formerly SP Technical Research Institute of Sweden

[13] SP Technical Research Institute of Sweden, (2012) *New standard for fire suppression systems in engine compartments of buses and coaches finally published*, media release, Borås, Sweden, 10 October 2012.

the product fulfils the standard. In November 2015, the test method was adopted in the United Nations Economic Commission for Europe, in regulation No. 107.[14] This mandated the installation and testing of fire suppression systems in bus engine bays in all single-deck, double-deck, rigid or articulated vehicles in Europe, for vehicles with capacity exceeding 22 passengers. In line with harmonisation of vehicle regulations, adoption of this standard is becoming more common around the world.[15]

2.33 Australia is a signatory to the agreement to harmonise our design rules with UN regulations. The applicable ADR does not specify the requirement to install integral fire suppression systems. Both TfNSW and RMS represent NSW on the Strategic Vehicle Safety and Environment Group (SVSEG). SVSEG is the senior vehicle standards-setting body, convened by the Commonwealth Department of Infrastructure & Regional Development, with representation from all jurisdictions and peak industry bodies, including bus organisations.

2.34 TfNSW has specified that all suppression systems are certified to the P-Mark SPCR 183 certification process, including systems that have undergone successful completion of the SP Method 4912.

2.35 The RISE Certification Board has advised OTSI that, due to the amount of the fire suppression systems to be installed on NSW buses, RISE will carry out an onsite audit of one randomly installed system on a passenger bus in Sydney in early 2017. This will be carried out in conjunction with the commencement of installation in the private bus fleet. During the audit RISE will check the following:

- That a proper risk assessment has been carried out of the bus type concerned. It will ensure that the risk assessment has been conducted by the fire suppression system manufacturer and that their personnel have documented experience for the task. It will also check that the risk assessment has been conducted in collaboration with the Contract Bus OEM

[14] The UN ECE is usually the starting place for vehicle regulation which is adopted worldwide.

[15] Bus fire safety research for reducing the risk of fires. (2016) Brandposten . Vol. 54. p.32.

supplier, the Contract Bus owner and TfNSW. Its main purpose is to demonstrate that the system design corresponds to the P-mark test reports.

- Review the installation drawings
- Review the actual installation
- Check that the installer is approved/licenced by the manufacturer
- Review the installer's signed declaration of conformity in which it declares that the system is installed and checked according to the risk assessment and the manufacturer's design manual.
- Sampling of the extinguishing agent in order to conduct a follow-up audit test at RISE to verify that the agent is the same agent that was initially tested.

2.36 **Future developments.** While installation of fire suppression will lower the level of risk of a bus fire developing, it is also important to reduce the risk of the fire starting in the first place. Preventative fire safety begins with the design and manufacture of the bus but also includes using fire retardant materials, servicing, maintenance and workshop inspection. RISE is currently developing an additional certification system in relation to bus fire safety. SPCR 190 will allow P-certification of vehicle manufacturers, operators and workshops with regard to fire safety.

2.37 According to RISE this new P-certification will enable the manufacturer, body builder, operator, authorized service centre or workshop to certify their fire risk mitigation process. The client must be able to assure the quality of the entire design/manufacturing/maintenance process in order to secure the highest level of safety that is practicable and to keep the risks as low as reasonably practical.

2.38 The addition of a more rigorous evaluation of fire safety risk assessments would be a way of further reducing the risk of bus fires.

Regulatory oversight in NSW

2.39 TfNSW is responsible for contracting bus services across NSW. TfNSW funds and contracts bus services through numerous metropolitan and regional bus service contracts. The contract is primarily a commercial document and relies on the RMS bus accreditation to attest that the bus operator has implemented an appropriate safety management system.

2.40 RMS is the road regulator in NSW. The RMS mandates that all operators of public passenger bus services be accredited in accordance with the *Passenger Transport Act 1990.* Each operator is required to meet the requirements of the Bus Operator Accreditation Scheme (BOAS) which is administered by RMS.

2.41 The BOAS requires the bus operator to be audited every three years by an RMS accredited auditor. The operator is also required to conduct an annual self-assessment and submit an annual self-assessment report to RMS. It also requires operators to manage the implementation, maintenance and improvement of key safety management systems.

2.42 An important requirement of the safety management system is that risk assessments are conducted for identified risks. STA have a documented safety risk assessment system. As part of the investigation STA provided risk assessments for: bus emergency evacuation, bus fire, bus engine bay fire and fire suppression systems on buses.

2.43 The STA risk assessment for bus engine bay fire from April 2015 is detailed and comprehensive.[16] Some of the existing risk controls in place included:

- Driver evacuation training
- Selected models of bus with fire suppression fitted
- On board fire extinguishers
- Emergency exits on bus
- Double doors in bus
- Maintenance servicing and inspection of plant
- RMS regulatory inspections
- Defect reporting procedures.

2.44 STA also identified some additional risk controls required which included:

- Training about the fire suppression system
- Driver incident and evacuation response skills training.

[16] STA Form 162 Safety Risk Assessment form – Bus engine bay fire and prevention 14 July 2015.

2.45 In this risk assessment, STA proposed the development and implementation of training material including different scenarios for bus operator's response in an incident or emergency.

Driver training

2.46 The driver received training upon joining the STA as a bus operator in April 2012. The training includes instruction in the event of a bus fire. The bus operator handbook states:

'If there is a fire anywhere on the bus, operators must:

> a. Immediately locate a safe place to stop, switch on hazard lights, press floor emergency/duress button.
> b. Inform Network Control Centre (NCC) of your location, and that there is a fire on the bus, then keep repeating the message. Location, problem and assistance required must be repeated continuously.
> c. When stopped:
>> i. Apply hand brake
>> ii. Select neutral gear
>> iii. Open all doors
>> iv. Turn off engine, master switch and emergency gas shutdown (gas buses).'[17]

The driver completed all the steps with the exception of turning off the master switch. This is a step often overlooked during emergencies and it would be preferable to have power to the engine shutdown when the ignition is switched off.

2.47 Training material is provided to drivers in video format, in the bus operations handbook and hands-on dry chemical fire extinguisher awareness. The theory in the use of a fire extinguisher was provided but not practiced. There had been no refresher training provided to this driver in the intervening time. The driver had not yet had any training in bus fire suppression systems yet had driven buses fitted with these systems. It should be noted that fire suppression systems that were retrofitted incorporate an additional visual driver interface

[17] STA Bus operations handbook –issue 12 July 2012.

panel. Maintenance instructions were widely circulated explaining the functionality of the driver warning and driver interface.

2.48 There is no legislative requirement about the frequency of refresher training for bus emergency procedures and use of fire extinguishers. In associated areas like first aid qualifications, the general requirement for retaining the qualification is a 3-year interval.

2.49 STA has identified the need to introduce training regarding engine bay fire suppression systems. The introduction of engine bay fire suppression systems into every STA bus is a significant change. Although it is an automatic system that does not require the driver's intervention, it is important for driver to understand the limitations and operation of the system.

2.50 The fire suppression system is located in the engine bay and fires can occur elsewhere on the bus. The timely intervention of a driver with a fire extinguisher is an important defence. Therefore, there is still the need for familiarity in the use of fire extinguishers even in buses fitted with a fire suppression system. Some form of practical training in fire extinguisher use may assist drivers to develop confidence and competency in dealing with live-fire situations.

High-visibility vests

2.51 The driver was not wearing a vest when first on the roadway (see *Figure 3*). The vest remained on the bus draped over the back of the seat where it was placed at the start of the trip. It is STA policy that high-visibility clothing is to be worn where appropriate. *'All staff must wear high-visibility authorised clothing and personal protective equipment when and where appropriate'*[18] and *'where there is a risk of personal injury due to working in the vicinity of moving traffic.'*[19]

2.52 The driver said that it would be easier if high-visibility clothing could be worn during driving. It is STA policy that high-visibility clothing is not to be worn whilst performing operational driving duties. *'Glare and reflection from high-*

[18] STA code of conduct. Bus Operations Handbook. PROC10.01. p.2.

[19] STA Safety Alert WI 50.08.31 *High Visibility Clothing'* issued August 2008.

visibility clothing can be both irritating and dangerous, causing accidents particularly at night, when raining, early in the morning and late in the afternoon.'[20] STA have stated that they have conducted a risk assessment on the wearing on high visibility clothing while driving. It was found that while it would reduce the chance of forgetting to wear the vest, it introduced additional risk.

Fires in higher risk environments

2.53 An aspect of this fire event was that it occurred in a location which increased the risk of injury to passengers and the driver. The Sydney Harbour Bridge carries a multi-lane highway (a tidal traffic flow with no lane barriers), high peak traffic loadings, close proximity to a rail corridor and above deck maintenance work. Any fire incident on the Sydney Harbour Bridge has the capacity to cause major disruption to localised peak hour transport as well as knock-on effect leading to potential gridlock in the CBD particularly affecting harbour crossings.

2.54 During this incident the response services were well coordinated. The Transport Management Centre, NSW Police Force, Fire and Rescue, RMS and the Ambulance Service all responded in a timely and effective manner.

Safety actions taken

2.55 Following the current incident, STA conducted an inspection of all Scania L113 series buses in their fleet. All engines were checked with special emphasis around the location where the auxiliary alternator cables cross the chassis rail. STA is revising the driving training program to increase focus on emergency evacuation and bus fires. It is also developing a training module for maintenance employees on fire awareness.

2.56 STA also completed the following actions:

- Released a safety alert for vehicle evacuation procedure
- Released a staff fire safety awareness video to depots

[20] Ibid.

- Revised the fire bus risk assessment
- Developed a bus evacuation risk assessment.

PART 3 FINDINGS

From the evidence available, the following findings are made with respect to the bus fire on a Scania L113CRL, registration MO 3726 that occurred on the Sydney Harbour Bridge, Milsons Point, NSW on 15 September 2016.

Contributory Factors

3.1 The fire started due to an electrical malfunction in the engine bay at the rear of the bus. The fire intensified, consuming flammable materials in the engine bay and eventually spread into the passenger saloon.

3.2 It is likely that the initiation of the fire was caused by a short circuit of the auxiliary alternator cables where they crossed the edge of the near side rear chassis rail. There was evidence of the B positive cable being severed and electrical arcing marks on the chassis rail in this vicinity.

3.3 Another short circuit likely occurred in the primary alternator cable when consequential damage occurred to its insulation following the development of the fire.

3.4 The main battery switch was left in the 'on' position after the driver shut the engine down and evacuated the bus. This meant that there was an ongoing supply of battery power to the source of the fire in the engine bay. This may have allowed the fire to intensify due to the continuous supply of thermal energy.

Other Safety Factors

3.5 The evacuation of passengers into an adjacent smoke-filled live traffic lane carried the risk of passengers being struck by vehicles travelling in this lane.

3.6 The driver had initial training in the use of fire extinguishers, although no refresher training had been undertaken since commencement of their employment.

3.7 Industry standards, such as the Australian Design Rules, do not require buses to be fitted with fire suppression systems. The bus was not fitted with an engine bay fire suppression system, however, the suppression system was scheduled to be installed in the month following the fire.

3.8 Despite the automatic operation of engine bay fire suppression systems, drivers need to have an understanding of the system’s operation to effect evacuation decision-making.

3.9 The application of the P-mark certification to bus engine bay fire suppression systems is a beneficial addition to the risk management process. Further development of the certification system into manufacture and maintenance processes has the potential to reduce the number of bus fires.

PART 4 RECOMMENDATIONS

It is recommended that the following safety actions be undertaken by the specified responsible entity.

State Transit Authority

4.1 Ensure that all buses are fitted with an operational engine bay fire suppression system.

4.2 Investigate the practicality of reconfiguring the shutdown process on all buses so that when the driver turns off the ignition the power supply to the engine bay is also shut down.

4.3 Examine the design and placement of electrical cabling on different model buses to reduce the likelihood of short circuit events occurring.

4.4 Conduct driver training at regular intervals to maintain drivers' familiarity with current emergency procedures.

4.5 Further develop driver training to ensure drivers receive some form of practical training in fire extinguisher techniques.

4.6 Include more detail in driver training for bus evacuation to include techniques for the protection and management of evacuating passengers into traffic.

4.7 Ensure drivers receive training in the operation of the engine bay fire suppression systems.

4.8 Review training for maintenance personnel to increase their awareness of likely fire initiation points with an emphasis on identifying probable fire initiators.

Roads and Maritime Services

4.9 Increase monitoring of operator bus maintenance procedures with respect to identified frequent fire initiation causes.

4.10 Promote the incorporation of fire detection and engine bay fire suppression system requirements into bus industry standards.

PART 5 APPENDICES

Appendix 1: Sources, Submissions and Acknowledgements

Sources of Information

- Roads and Maritime Services
- RISE Research Institutes of Sweden
- State Transit Authority
- Transport for NSW

References

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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:

- Driver of bus
- Roads and Maritime Services
- RISE Research Institutes of Sweden
- State Transit Authority
- Transport for NSW

Submissions were received from all DIPs:

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.

Acknowledgements

Cover Photos: Bus fire on Sydney Harbour Bridge.

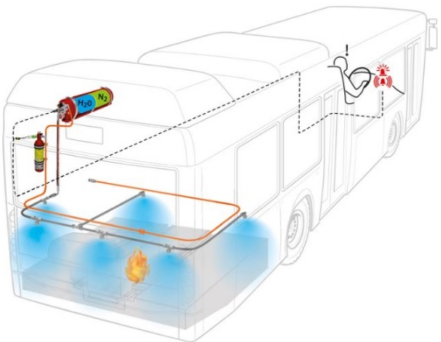
Source: Photos sourced from Twitter (L: Alex Heath. R: Liz Berger). Used with permission.

Appendix 2: Fire suppression systems

The installation of fire suppression systems on buses is an effective option for reducing the consequences of fire in and around the engine, or at least suppressing fires until emergency services arrive. Successful operation of such systems may mitigate or eliminate the risks associated with the use of portable extinguishers.

The fire suppression systems fitted to NSW buses consist of two cylinders located towards the rear of the bus. One cylinder contains compressed nitrogen gas which is distributed in two plastic pressurised detector tubes to the engine bay and transmission. The other cylinder contains water with a foaming additive which is distributed along two metal sprinkler pipes, also to the engine bay and transmission.

Detection and activation of the system takes place pneumatically. In the event of a fire, the pressurised detector tube bursts and the resultant drop in pressure activates a valve on the extinguishing container. A pressure switch on the detection gas bottle indicator gives both an audible and a visual alarm to the bus driver via a display panel. The system operates independently of the bus power supply.



When the system is activated, the water in the metal piping is discharged under pressure as a mist from small nozzles along the sprinkler pipe throughout the engine bay and over the transmission, directed into areas of known heat sources. The water mist (known as high-fog) provides a cooling effect and interrupts the supply of oxygen to the fire. The water mist also deposits a layer of foam over flammable oil products that tend to collect in depressions on and around the engine.

The activation of the fire suppression system is automatic, it alerts the driver who then takes the usual evacuation and shut down procedures depending on the bus model.