Office of Transport Safety Investigations

BUS

Safety Investigation Report

Bus Fire MO5103
Campbelltown, NSW
16 August 2021

Published August 2022

BUS SAFETY INVESTIGATION REPORT

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Campbelltown, NSW

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THE OFFICE OF TRANSPORT SAFETY INVESTIGATIONS

OTSI is an independent NSW authority which contributes to the safe operation of bus, ferry and rail passenger and rail freight services in NSW by investigating safety incidents and accidents and transport safety risks, identifying system-wide safety issues and sharing lessons with transport operators, regulators and other stakeholders.

OTSI is empowered under the *Transport Administration Act 1988* to investigate rail, bus, and ferry accidents and incidents in accordance with the provisions of the *Passenger Transport Act 1990* and *Marine Safety Act 1998*. It also conducts rail investigations on behalf of the Australian Transport Safety Bureau under the *Transport Safety Investigation Act 2003* (Cth).

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Evidence obtained through an OTSI investigation cannot be used in any subsequent criminal or disciplinary action. However, a regulator can undertake its own investigation into an incident OTSI has investigated and coronial inquiries can obtain access to OTSI information.

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OTSI investigators normally seek to obtain information cooperatively when conducting an investigation. However, where it is necessary to do so, OTSI investigators may exercise statutory powers to conduct interviews, enter premises and examine and retain physical and documentary evidence.

Publication of the investigation report

OTSI produces a written report on every investigation for the Minister for Transport, as required under section 46BBA of the *Passenger Transport Act 1990*.

Investigation reports strive to reflect OTSI's balanced approach to the investigation, explaining what happened and why in a fair and unbiased manner. All DIPs will be given the opportunity to comment on the draft investigation report.

The final investigation report will be provided to the Minister for tabling in both Houses of the NSW Parliament in accordance with section 46D of the *Passenger Transport Act 1990*. The Minister is required to table the report within seven days of receiving it.

Following tabling, the report is published on the OTSI website – www.otsi.nsw.gov.au – and information on the safety lessons promoted to relevant stakeholders.

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EXECUTIVE SUMMARY

On the morning of Monday 16 August 2021, bus MO5103 caught fire on Kellicar Road, Campbelltown, in the vicinity of Macarthur Square Shopping Centre. Immediately before, the bus was travelling southbound with the driver and three passengers. One of the passengers observed smoke in the back of the bus and the driver was alerted.

The driver stopped the bus in a safe location and all onboard safely evacuated. Smoke escalated to fire, which spread and engulfed the bus. Fire and Rescue NSW attended and extinguished the fire. The bus was destroyed.

The investigation identified that the initiating source was within the roof-mounted air conditioning (A/C) system. The A/C system was manufactured by DENSO Automotive Systems Australia, controlled by a Thoreb M2 programmable node.

The investigation found damage associated with electrical arcing in the vicinity of the control node, specifically in the region of the main connector block and its associated wiring harness. While the specific failure/s leading to the fire could not be determined, several potential contributing factors were examined.

Both DENSO and the involved bus operator initiated engineering inspections of similarly configured buses immediately after the incident. Inspections within the operator's fleet indicated problems in several other buses, including issues in the wiring harness between the main A/C connector blocks, security of terminals and evidence of terminal discolouration within the main connector block.

The investigation identified safety improvement opportunities in routine inspection of roof-mounted A/C systems' wiring integrity and security, asset maintenance systems and accreditation scheme assurance processes.

Several Recommendations resulted from the investigation. Operators of all model buses, configured with a similar A/C configuration, should ensure that manufacturer specifications for contact resistance limitations of the Tyco S2 connector be incorporated into asset management and maintenance regimes. It was also recommended that Transport for NSW (TfNSW) review current asset management requirements, to apply a more comprehensive safety risk management and regulatory framework for long-term asset management. In addition, a Recommendation was made to TfNSW to review the framework for asset systems configurations, to ensure that critical design decisions related to high current systems made during bus procurement, including Failure Mode Effect and Analysis, were documented and available to operators and maintainers.

PART 1 FACTUAL INFORMATION

The occurrence

1.1 On the morning of Monday 16 August 2021, bus MO5103 was operating service 896 between Oran Park and Campbelltown, New South Wales (NSW), departing Oran Park at 1008.[1]

Approaching Macarthur Square Shopping Centre in Campbelltown, the bus was travelling south with a driver, two adult passengers, and a young child onboard.

1.2 At 1049, the bus driver was stopped at the traffic light-controlled intersection on Gilchrist Drive, waiting to turn right into Kellicar Road, when the young child notified an adult passenger of smoke in the back of the bus body.

The adult passenger, from their seated position, immediately advised the driver verbally of the smoke and gestured to the back of the bus.

1.3 The driver later reported at interview that when advised of the smoke, they considered the risks if the bus was stopped and passengers evacuated immediately, in that location. Passengers would have had to exit through traffic and may be injured in a collision with another vehicle. The driver decided to continue into Kellicar Road, to a safe location.

1.4 While waiting for the traffic lights to change, a fire alert for the engine bay fire suppression system activated on the display panel beside the driver, accompanied by an aural alarm.

Within 10 seconds of the smoke notification from the passenger, the traffic lights changed to green, and the driver turned the bus right into Kellicar Road.

1.5 The driver later reported that they were aware that there was an overpass for the Macarthur Square Shopping Centre ahead and did not want to stop the bus underneath, as their vehicle may be on fire.

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

The driver determined that the safest place to stop was outside a large brick building, prior to the overpass and main shopping centre area. The driver assessed that the passengers could safely disembark and if the bus was alight, the risk of potential injury to bystanders, and damage to infrastructure, would be reduced.

1.6 Thirty seconds later, at 1049:29, the driver stopped the bus on the left side of Kellicar Road, before the Macarthur Square Shopping Centre overpass and designated bus stop.

The driver opened their compartment then the front exit. At that time, all passengers were already moving forward, down the aisle, to evacuate the bus.

1.7 All three passengers evacuated safely via the front exit, onto the footpath, followed by the driver. The driver directed the passengers away from the front of the bus, along the footpath towards the shopping centre. The driver then walked to the rear of the bus.

1.8 The driver checked underneath the engine bay for smoke. On not sighting any smoke there, the driver returned to the front of the bus, instructing the passengers on the footpath to remain clear. The driver then stepped back into the bus.

1.9 The driver visually checked again that all passengers had evacuated, then retrieved their own mobile phone from within the driver's compartment before exiting. The driver could not use the two-way radio in the bus to contact their Operations Control Centre (OCC), due to the escalating smoke in the passenger saloon area, so the driver retrieved their mobile phone as an alternative means of communication.

The driver later reported observing that smoke in the saloon area had significantly increased, and visibility decreased, at that time.

1.10 From the footpath, the driver used their mobile phone to call the OCC. While speaking with the OCC, the driver re-entered the bus, reporting smoke within.

The OCC confirmed with the driver that all passengers had safely evacuated then directed the driver to evacuate the bus and call emergency services.

1.11 The driver later reported that while calling emergency services from the footpath, they observed dark smoke, fire and sparks coming from the top of the bus, in the vicinity of the roof-mounted air conditioning (A/C) pod. This was within five minutes of the bus stopping.

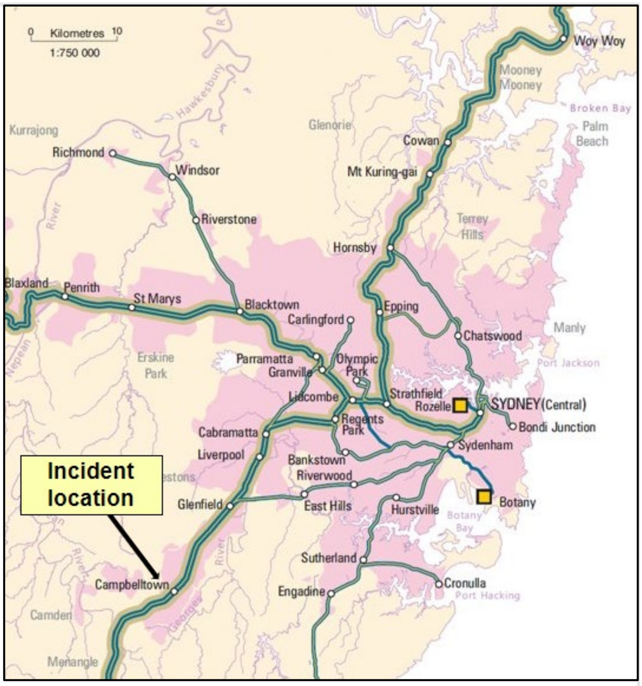
1.12 As Fire and Rescue NSW arrived, the smoke quickly escalated into flames, engulfing the bus. In addition to the intense fire, large plumes of thick, dark grey smoke emitted from the bus. Fire and Rescue NSW extinguished the fire. The bus was destroyed.[2]

1.13 The bus operator instructed Fire and Rescue NSW, via phone, on the bus battery isolation procedure after the fire was extinguished. Isolation was completed as standard procedure for a vehicle accident by Fire and Rescue NSW, to isolate the battery source and ensure that no power could travel through any electrical circuits.

Incident location

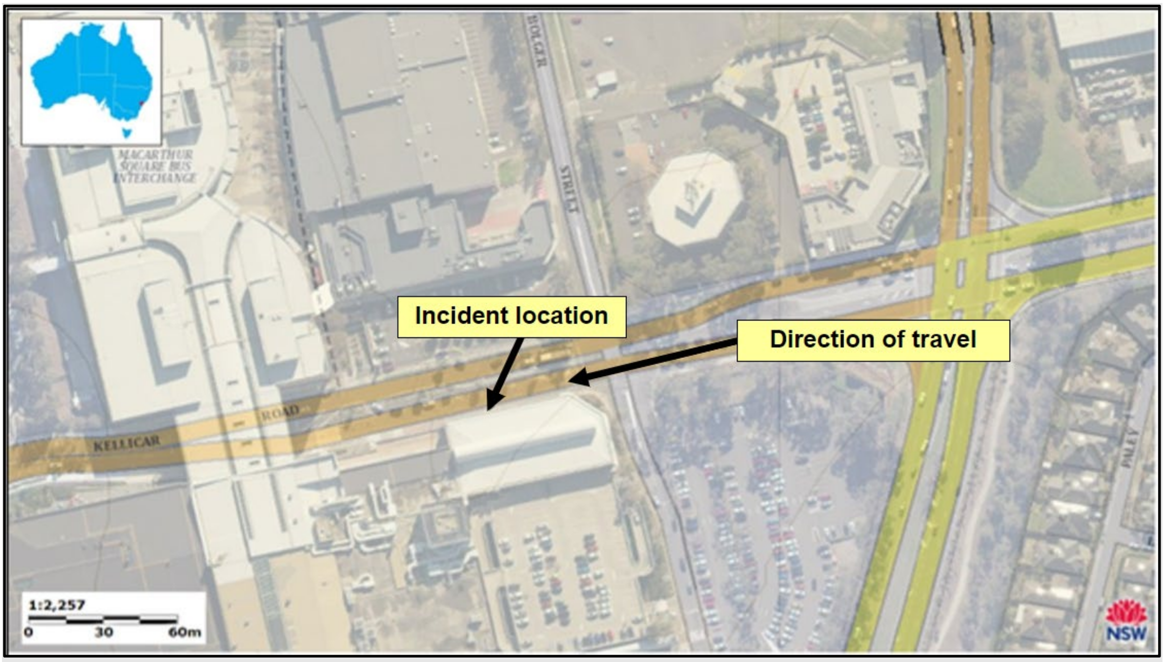
1.14 The incident occurred on Kellicar Road, Campbelltown, which is approximately 44 km south-west of Sydney's CBD (Figure 1). The bus was positioned next to a large brick building which was unoccupied at the time of the incident (Figure 2).

[2] Due to damage sustained in the fire, the bus cannot be repaired. There was significant destruction to one or more sections. Examples of this category are:
• The bus is completely burnt out
• The engine bay is burnt out and the rear passenger area of the bus is partially damaged
• It is not economically viable to repair the bus.



Source: Geoscience Australia. Image annotated by OTSI

Figure 1: Incident location



Source: SIX Maps. Image annotated by OTSI

Figure 2: Incident site

Environmental conditions

1.15 On Monday 16 August 2021, the Bureau of Meteorology recorded a temperature range of 7°C to 21.7°C at the Campbelltown (Mount Annan) weather station, about 3.1 km northwest of the incident.

The morning was sunny and dry, with a recorded temperature of 16.6°C and a westerly wind of 11 km/h at 0900.

1.16 The investigation determined that environmental conditions were not a contributing factor to this incident.

Driver information

1.17 The experienced driver held a valid Transport for NSW (TfNSW) Bus Driver Authority and Heavy Vehicle licence. They had driven for another bus company before joining this operator.

1.18 The driver had successfully completed emergency response training with the current operator, including emergency response actions.

1.19 The driver reported that on beginning their shift, when starting up the involved bus, the ambient temperature was cool, and the bus A/C was not required.

The driver did not alter the bus's A/C system setting on the morning of their shift. They could not recall if the A/C system was on at the time of the incident.

1.20 The driver later reported at interview that they experienced an increased cognitive workload after the passenger's smoke notification and had to think and act quickly to manage the situation.

1.21 The driver reported that the engine fire suppression system 'FIRE' alert supported the passenger's observation of smoke within the back of the bus. The driver also reported that the alert assisted their own situational awareness for the emerging situation.

1.22 After disembarking, the driver walked to the back of the bus, expecting to see smoke in the engine bay area, based on the available indications. The driver reported that they had received training that the engine bay was a potential fire initiation location, which supported their expectation that it was the source.

However, there was no smoke in that area when checked, or smoke visible external to the bus, so the driver considered that the fire was located elsewhere, within the bus. Shortly after, the driver observed dark smoke, fire and sparks coming from the exterior roof of the bus, in the region of the A/C system.

Bus information

1.23 The bus was a MAN Automotive (Australia) Pty Ltd 18.320 HOCL-R-NL model, registered in NSW as MO5103. It was fitted with a Custom Coaches CB80 body manufactured in June 2012 and powered by a six-cylinder turbo charged diesel engine. The bus was rigid, with two entry/exit doors, and was 12.5 m in length.

1.24 The bus was equipped with an Engine Bay Fire Suppression System (EBFSS). The water mist system consisted of an extinguisher cylinder and a detection cylinder mounted behind a side panel towards the rear of the bus. A pipe system with spray nozzles and a detector hose was routed around the upper part of the engine bay.

There was a system display panel located next to the driver's position to alert them if the system had a fault or activated.

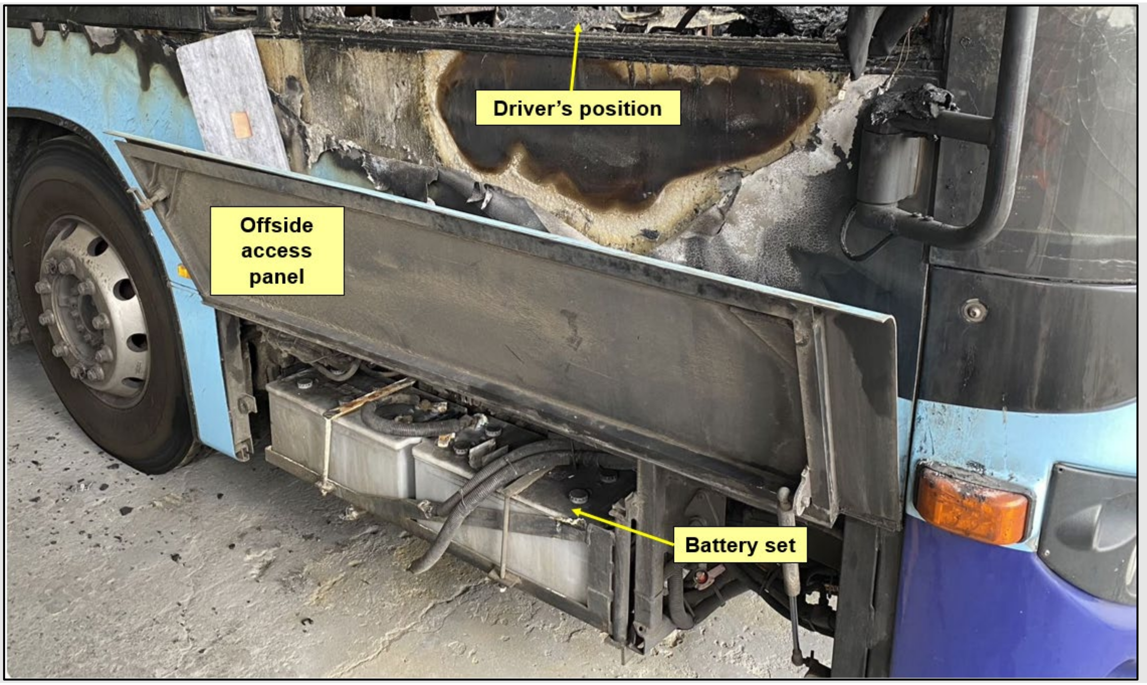
The EBFSS had two notifications to the driver and two distinct audio tones for:

- Fault (one pressure switch has lost continuity)
- FIRE (both pressure switches have lost continuity).

The wiring for the driver's EBFSS alert system was routed along the upper A/C ducting panel on the offside[3] of the bus.

[3] The left side when looking forward in the bus is the nearside. The right side is the offside.

1.25 The bus battery isolation switch was located adjacent to the battery set on the front offside of the bus, under an external access panel (Figure 3).



Source: OTSI

Figure 3: Bus battery set location (post fire image)

1.26 The bus operator did not lock this access panel, nor require or train its drivers to isolate the bus battery in an emergency, due to assessed hazards and risks (see *Operator information*).

Technical information

1.27 The A/C system on the involved bus was a DENSO Automotive Systems Australia LD8i model, controlled by a Thoreb M2 programmable node as the Electronic Control Unit (ECU). The circuit breakers were supplied by DENSO. The Socket (S) Connector (S2 connector) lead harness were supplied by Thoreb.

1.28 The A/C system was installed by an auto electrical company for the bus body manufacturer at the time the body was built in 2012.

1.29 The DENSO A/C pod was externally roof-mounted with four condenser fan motors and eight blower motors. It utilised two single row heater cores providing reheat. (Figure 4 and Figure 5).

Source: DENSO

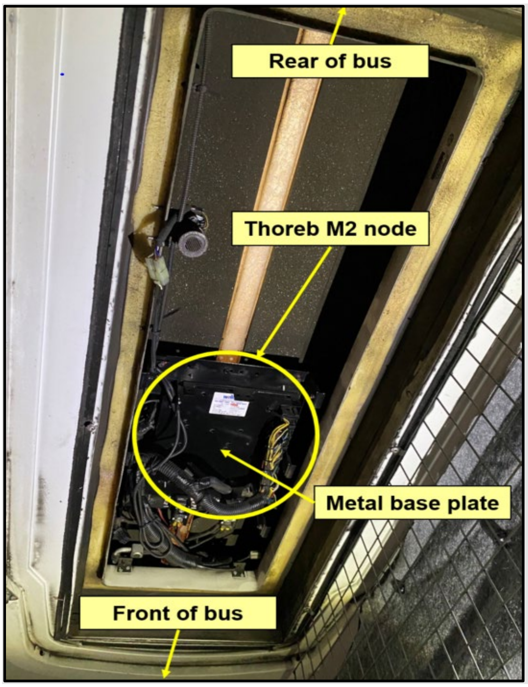
Figure 4: DENSO roof mounted A/C pod

Source: Busabout. Image annotated by OTSI

Figure 5: Roof-mounted A/C pod location on MO5103

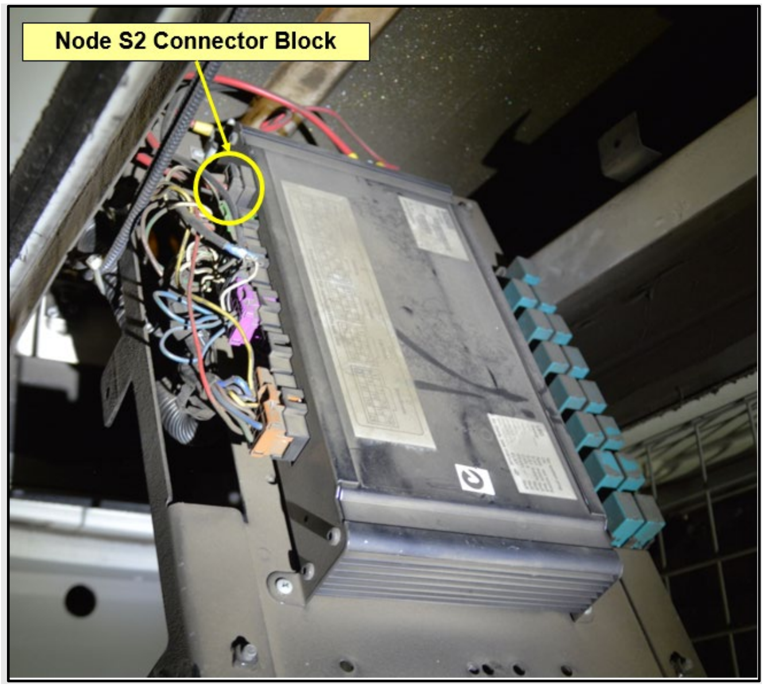
1.30 Below the roof-mounted pod, there was a hinged air inlet grill, located inside the bus, above the passenger aisle.

Behind the grill was a filter, then the Thoreb M2 node and wiring harness installed in a recess (Figure 6 and Figure 7 of exemplar bus). The node was on a hinged panel to enable it to be pivoted out of the recess for maintenance.



Source: OTSI

Figure 6: Roof location of Thoreb M2 Node in A/C system (in normal operating position with grill open)



Source: OTSI

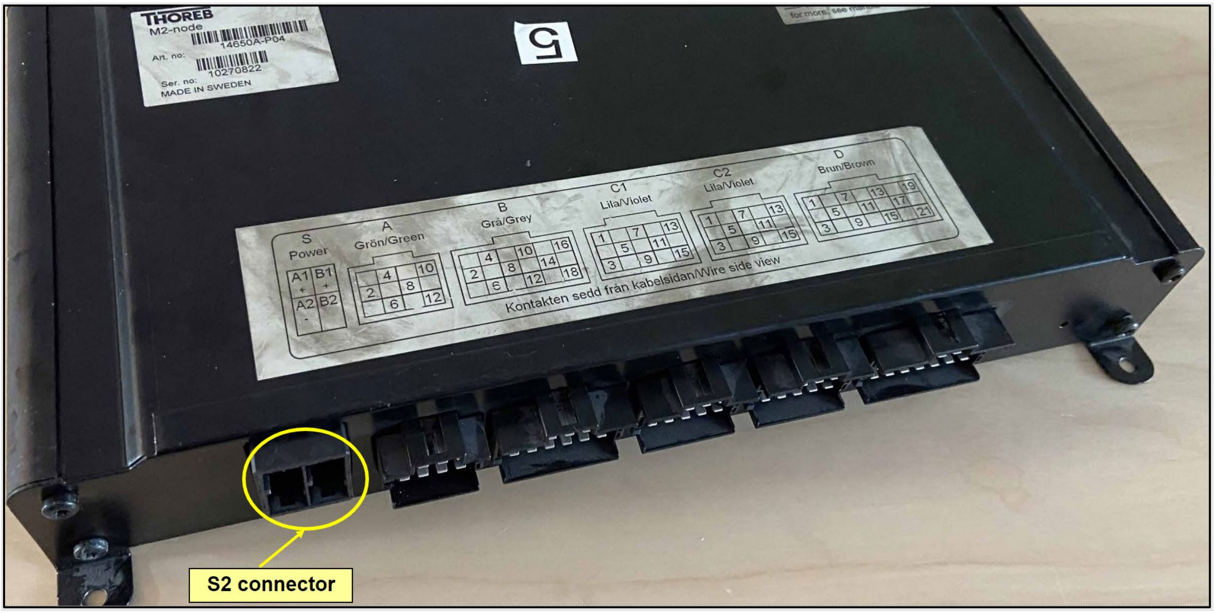
Figure 7: Location of Thoreb M2 Node and S2 connector block in A/C system (node dropped from recess)

1.31 The Thoreb M2 node was designed to be part of a multiplex electrical system, to minimise the amount of cable and connectors, and replace relays and fuses.

The node had a 32-bit processor and 48 kilobytes of RAM, with a total current capacity of 90A. The allowable operating temperature was -40 to 70°C.

The node was encased in black anodized aluminium (Figure 7 and Figure 8), and had six connectors:

- three for inputs and outputs
- two for communication
- one S2 connector for power supply.



Source: DENSO. Annotated by OTSI

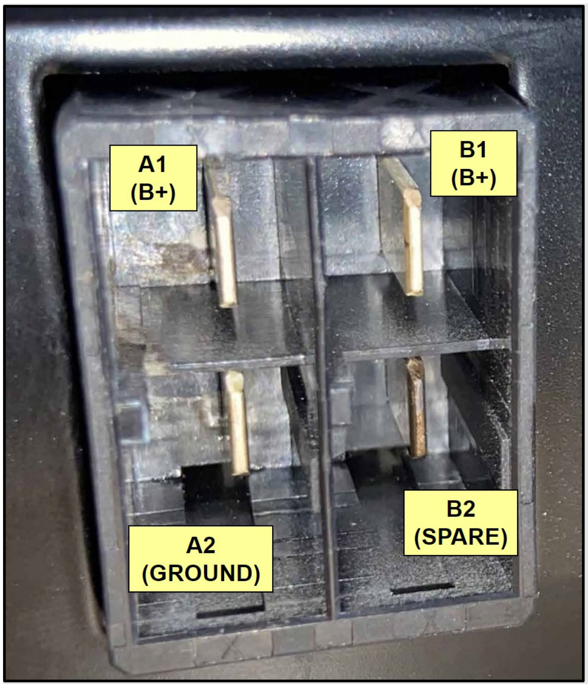
Figure 8: Exemplar Thoreb M2 node – external view

1.32 The S2 connector, which provided power to the M2 node, was a Tyco D-5200Mα High Current Type, with a voltage rating of 630V AC and operating temperature of -55°~+105°C.

The Tyco specifications stated that the durability rating of the S2 connector was limited to 25 cycles. As such, the S2 connector could only be removed and replaced to a maximum of 25 times in order to meet the requirement of contact resistance.

There were four copper alloy contacts/receptacles and associated tab posts, finished in silver plating with underplated nickel. The housing was UL 94V-0 rated, glass fibre reinforced polyester.

The node had two separated power supply connections in the S-Connector (two B+ (A1 and B1)) and Ground (A2). The fan and blower current were directly wired to ground within the A/C system. In this A/C configuration, the bottom right receptacle (B2) was not in use (Figure 9).



Source: DENSO. Image annotated by OTSI

Figure 9: Exemplar Tyco D-5200Mα High Current Type S-Connector showing tab posts

1.33 In this configuration, the wires into A1 and B1 were individually connected to 40A 12V auto reset circuit breakers, then connected to the vehicle battery through the main 150A fuse.

The battery harness and main fuse were supplied by the A/C system installer.

1.34 The 40A 12V circuit breakers for the wiring to A1 and B1 were thermal reset, Type I circuit breakers, which cycled or continuously reset until the overload was corrected.

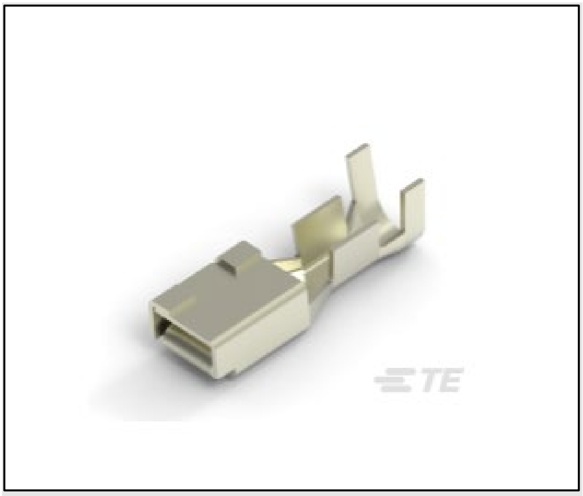
1.35 The Thoreb design specification, outlined in the *Thoreb ELSY Construction and Installation Directions* (Section 3: 'Power Supply and Ground Connections of the Nodes', sub section 3.1), stated that:

Each node shall get its power supply via two separate positive conductors from some type of distribution centre. Each node's power supply should be connected to fuses of their own. Fuses are chosen with regard to the conductors' current capacity (measured in amperes). The node's inputs and outputs are protected against overload and short-circuit, which means that the fuses' main purpose is to protect the node's supply cable harness'.

1.36 It was reported that the body builder of MO5103 was provided several iterations of the Thoreb document, and the power and fuse specifications remained unchanged. The referenced document was provided as part of general body builder training material from the introduction of the ELSY product.

1.37 There was no evidence available to the investigation on the final system design selection of fuses or auto-resettable circuit breakers.

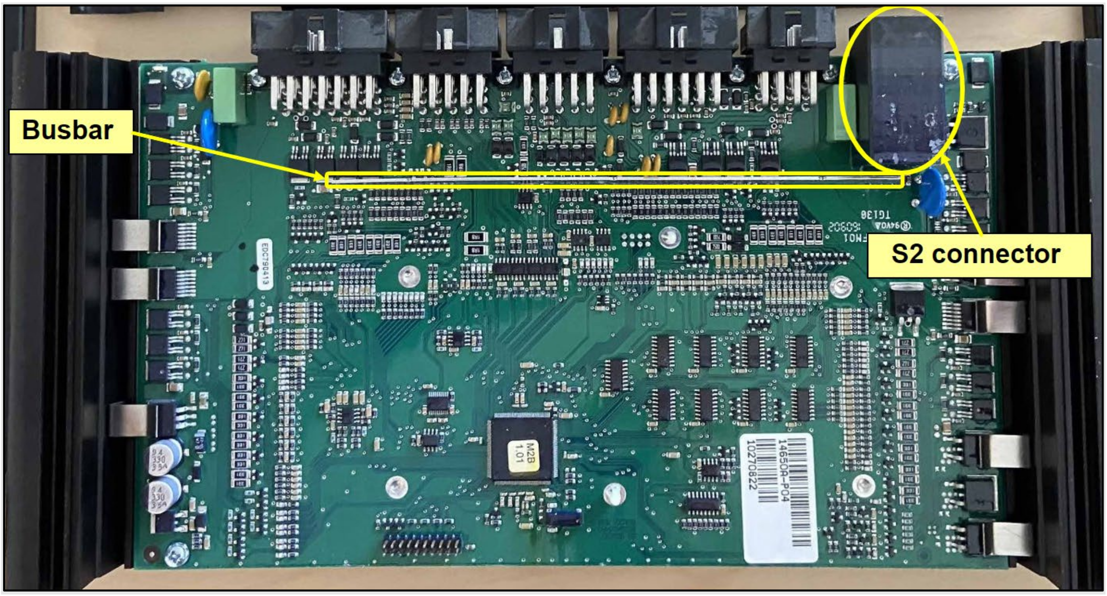
1.38 The Thoreb approved contacts for connecting wiring/cables to the M2 node were TE Connectivity Dynamic D-5 receptacle crimp type contacts with silver plating (Figure 10).



Source: TE Connectivity

Figure 10: TE Connectivity Dynamic D-5 Receptacle connector contact

1.39 The Thoreb M2 node was configured with a single metal electrical busbar[4] (Figure 11).



Source: DENSO. Annotated by OTSI

Figure 11: Thoreb M2 node circuit board

1.40 The driver interface for the A/C system was accessible via a Thoreb C90 unit. The C90 unit had the following functionality:

- display operating information
- A/C system communication and control via the M2 node
- maintenance management
- data download and A/C system reprogramming.

There were two driver selection options for the bus's climate set up, via the C90 unit:

- Defog: either Off or On
- A/C: either Off or On

[4] A busbar is an electrical conductor used to collect and distribute electrical power. It is a metallic strip that carries incoming power and distributes to all connected outgoing conductors.

Source: Busabout

Figure 12: Thoreb C90 unit climate setup display

1.41 The A/C system was pre-set to operate at 22°C if 'on'.

On the CB80 body, the A/C 'on' signal was controlled by the body multiplex system. The signal turned 'on' once the bus was running. On certain chassis, the signal was governed by the coolant temperature. The investigation could not determine if the involved chassis' A/C 'on' signal was coolant temperature governed.

Operator information

1.42 The bus operator was Busabout, which operated and maintained a fleet of buses owned by Transport for NSW (TfNSW), under contract as an accredited operator (see *Asset owner requirements*).

1.43 The operator had a driver training program in place which included annual emergency response training.

1.44 The operator's fleet included buses with a battery isolation switch that was accessed via an external panel on the front offside of the bus.

1.45 The bus operator had assessed that the hazards and risks associated with a driver accessing the external access panel and isolating the bus battery were unacceptable. This included the potential for injury as result of a collision with a passing vehicle.

The operator did not lock the external access panel for the battery isolation switch to allow for emergency services personnel to have immediate accessibility, if required.

System maintenance history

1.46 Before allocation to the involved operator, the involved bus was operated and maintained by another operator from initial entry into service. This was due to the region's contract which was transferred in June 2014.

1.47 Examination of the bus's servicing and maintenance history, provided by the involved operator, presented several issues with MO5103's A/C system.

On 2 October 2014, an A/C service technician identified that the A/C compressor was faulty and not pumping. The compressor was replaced and during system checks, the Thoreb M2 node was found to be faulty. Thoreb replaced the M2 node on 14 October 2014. Records indicate that this M2 node was in place at the time of the event in 2021.

1.48 From 1 January 2020 to the date of the incident, several issues arose, and seven different technicians were recorded as conducting A/C system repairs on M5103 (Figure 13).

Date	Recorded issue	Rectification	Technician
02/01/2020	3 evaporator fans not working	3 evaporator fans replaced and rewired	A
21/01/2020	Blower fan not blowing cold air	New blower fan fitted	B
27/08/2020	A/C faulty	Repaired [no further details]	C
22/09/2020	Lower A/C idler pulley	Idler pulley replaced and rewired	D
23/11/2020	2 condenser motors	Removed and replaced 2 condenser motors	E
02/12/2020	A/C not working	Plugged in temperature sensor	F
04/12/2020	[Not stated]	Replaced 1 nearside and 1 offside evaporator fans	G
07/12/2020	A/C not working	Plugged in temperature sensor	F
15/12/2020	A/C not working	Removed and replaced evaporator and condenser fans [no further details]	E
16/12/2020	A/C high pressure fault	Replaced 5 evaporator motors and 3 condenser motors	E

Figure 13: MO5103 A/C system maintenance records data

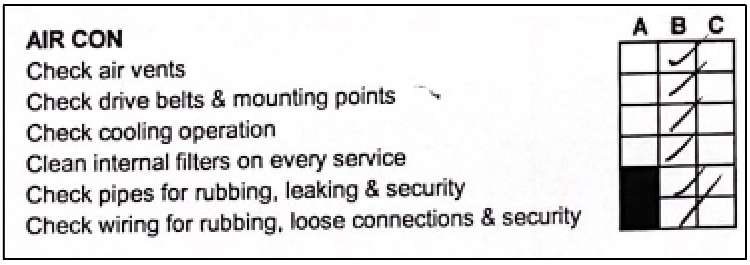
1.49 The bus was last serviced by the operator on 26 July 2021, in accordance with the documented maintenance schedule. The bus's odometer was recorded as 742,991 km at that time, and it was 5,155 km and 54 days since the last service.

1.50 The operator's electronic maintenance records documented that a B Service and visual inspection of the bus fire suppression system were conducted. According to the electronic record, no repairs on the A/C system were conducted. A copy of the associated paper service sheet was unable to be located during the investigation.

1.51 The last service included the following maintenance for the A/C system:

- Check air vents
- Check drive belts and mounting points
- Check cooling operation
- Clean internal filters
- Check pipes for rubbing, leaking and security
- Check wiring for rubbing loose connections and security.

1.52 The operator's service sheets were formatted with tick boxes next to each item (Figure 14). The sheets did not reference maintenance instructions or service manual for specific inspection processes or procedures, or Original Equipment Manufacturer (OEM) requirements.



Source: Busabout

Figure 14: Exemplar MAN Service Sheet extract for bus A/C system showing B Service completed

1.53 In September 2020, DENSO issued a Service Bulletin for bus A/C systems, for service dealers and operators, related to the disinfecting and antibacterial measures being taken in bus interiors, in response to COVID-19. The Service Bulletin noted that if water or chemicals contacted electrical components of the A/C system, the system may malfunction or catch fire. A number of precautions were documented, to mitigate the associated risks.

The precautions documented in the Service Bulletin were implemented by the bus operator.

Air conditioning system configuration history

1.54 This A/C system configuration (DENSO LD8i model with Thoreb M2 node) was installed in more than 330 bus bodies in Australia, for various manufacturers by different auto electrical contractors, from 2008 to 2014.

This configuration was installed in 16 buses in 2012, including the involved bus, MO5103. Most installations occurred in 2009 and 2010, with 126 and 118 respectively in those years.

1.55 DENSO reported that the A/C system with the DENSO LD8i model roof unit was designed to run with a DENSO ECU, not a Thoreb node. The DENSO LD8i Installation Manual contained circuit/wiring diagrams for a DENSO ECU.

Available data indicated that Thoreb M and M2 nodes replaced DENSO ECUs in the DENSO LD8, LD8i and LD8u A/C systems in TfNSW assets, commencing in 2005.

DENSO was involved in the A/C system configuration change and submitted a tender proposal which included a Thoreb node, to meet the requirements of TfNSW. It was reported that the integration of the Thoreb control node was conducted collaboratively between Custom Coaches, DENSO and Thoreb.

Thoreb prepared control software to meet specification requirements issued by DENSO. DENSO also issued the A/C installer with retrofitting instructions for the new configuration.

Asset owner requirements

1.56 The involved bus was purchased in compliance with Bus Operator specifications, registered and paid by the Bus Operator and is required to be transferrable to any successor operator, which occurred in 2013.

1.57 TfNSW bus specifications for new buses were determined by the TfNSW Bus Procurement Panel. The specifications for the involved bus, on procurement, included a multiplexed A/C system. The involved A/C system configuration met the multiplex requirements.

1.58 Introduced on 1 July 2005, TfNSW had the Bus Operator Accreditation Scheme (BOAS) in place at the time of the event.

Under the *Passenger Transport Act 1990*, all operators of public passenger bus services required accreditation to be able to provide services legally in NSW, unless otherwise specified by TfNSW.

The key elements of BOAS included:

- requirement to apply for reaccreditation and to renew accreditations every three years
- requirement that only licensed (Motor Vehicle Repairer's Licence Authority) repairers perform safety critical work on buses (brakes, suspension and steering)
- Annual Self-Assessment Reports
- Independent audits (by TfNSW).

1.59 The BOAS Independent Audit included a requirement to review the operator's maintenance program to ensure it was 'consistent or better than the manufacturer's specifications'.

1.60 The Asset Management Branch (AMB) (formerly the Asset Standards Authority (ASA)) was documented as the TfNSW authority on network design and standards for transport assets across NSW.

1.61 The AMB was responsible for developing engineering governance and frameworks to support industry delivery in assurance of design, safety, integrity, construction, and commissioning of transport assets for the whole asset life cycle.

The AMB was also responsible for providing the standards that industry organisations used to deliver projects and manage transport assets across NSW in a more innovative, safe, and efficient manner.

1.62 The AMB published Standard '*Mounting and Installation of Electrical Equipment'*[5] with the stated purpose to 'contribute to the reduction in electrical related failures and electrical initiated fires on buses'. The document provided general principles and requirements for constructional details, mounting, cabling and installation of electric equipment for buses.

1.63 The Standard stated the following under the heading 'Maintenance':

> The minimisation of life cycle costs and maximisation of operational availability of equipment and systems are important requirements. These requirements should be met by a combination of high reliability, minimal maintenance requirements and ensuring the ease of any necessary maintenance (maintainability).

1.64 The Standard included the following requirements:

- cables or looms or harnesses shall be secured adequately to prevent movement, chafing or vibration while in service.
- a battery isolating switch shall be provided adjacent to the batteries to isolate power to the vehicle.

1.65 The 2019 AMB electrical Standard related to new or substantially modified bus electrical installations and was not retrospective. TfNSW reported that requirements applicable to buses were contained within the procurement specifications and any referenced standards for the original design and construction, and maintenance requirements (schedules) should be provided by the OEM and applied by the maintainer (operator).

1.66 TfNSW stated that 'maintenance requirements should have been provided by the OEM and suitable maintenance procedures should be developed by the maintainer to ensure compliance. It would be expected that as new equipment is introduced appropriate maintenance requirements would be

[5] T BU FL 01701 ST, Version 1.0, issue date 03 April 2019

obtained from that equipment OEM, and these worked into the bus overall maintenance requirements by the maintainer (operator)'.

1.67 At the time of the event, bus battery isolation switch locations varied in TfNSW assets, with some makes/models having battery isolation functionality available directly from the driver's position. Other buses were fitted with a battery isolation switch under an access panel on the offside of the vehicle.

Some operators locked this access panel and provided drivers with an access key and training on how to isolate the batteries. Other operators, including the one involved in this incident, kept the access panel unlocked, with no expectation or instruction that the driver isolate the battery in a thermal event, due to potential hazards and risk of injury.

Other regulatory requirements for buses in Australia

1.68 At the time of the event, the National Heavy Vehicle Regulator (NHVR) was Australia's regulator for heavy vehicles. The involved bus was approved to operate under the Heavy Vehicle National Law.

The NHVR Maintenance Management Accreditation, which was not a requirement for TfNSW contracted operators, encouraged heavy vehicle operators to maintain their vehicles in good condition, and diagnose and rectify faults.

The Accreditation required that 'maintenance and repairs are undertaken by only people who have suitable qualifications or experience to competently complete any maintenance or repair tasks or do so under supervision'.

1.69 In Victoria, the transport safety regulator was Transport Safety Victoria (TSV), which encompassed Bus Safety Victoria.

To operate a bus service in Victoria with seating positions for 10 or more adults (including the driver), the operator was required to be accredited. This included the requirement for a Maintenance Management System (MMS), based on each operator's own operating conditions, risks, incident history and determined safety objectives.

A requirement of the MMS was to establish processes to identify, record, report, and address defects in buses. An MMS must contain the following processes and treatments for defects:

- method(s) for preventing a bus from use until any defect(s) are repaired.
- references must include, but were not limited to, vehicle manufacturer's specifications, national heavy vehicle inspection manual and any applicable legislation or vehicle standards, for the development and maintenance of inspection checklists and for defect identification.
- recording and reporting procedures for any defect discovered during operation, so far as is reasonably practicable, to ensure that appropriate action was taken in relation to that defect.

Related occurrences

1.70 While this investigation into the incident on 16 August 2021 could not definitively determine if compromised wiring in the A/C system contributed, it was determined to be a potential factor.

OTSI investigations have identified that cables, looms and/or harnesses, ineffectively secured to prevent movement, chafing or vibration while in service, contributed to several bus fires within the five-year period preceding this incident. These investigations included:

- Bus fire, Dudley, 28/04/2016
- Bus fire, Sydney Harbour Bridge, 15/09/2016
- Bus Fire, Homebush, 08/02/2017
- Bus fire, Sawyers Gully, 06/03/2017
- Bus fire, Valley Heights, 30/06/2017
- Bus fire, Glebe, 11/01/ 2021.

1.71 The OTSI investigation[6] into the State Transit Authority bus MO1504 fire on the Sydney Harbour Bridge on 6 May 2016 identified that a failed component, on a circuit board in the roof-mounted A/C system, was the most likely ignition source. It was likely that the component was either damaged during manufacture or when installed in the bus.

The A/C system was not the same configuration as that in the involved bus on 16 August 2021.

1.72 OTSI has collated and published summaries of reported bus fire incidents in NSW since 2012. The most recent annual summary of bus fires in NSW was published in January 2021.[7] In 2020, most fire and thermal incidents (57%) originated in the wheel well area. There were 26% of incidents in engine bay area and 17% in the bus body.

1.73 All body incidents in this period were attributed to electrical malfunction or failure. The 12 electrical incidents had a wide variety of origins: wiring insulation abrading, A/C control gear, high resistance connections, water ingress to electrical components and faulty wiring.

1.74 There were seven A/C system related thermal events reported in 2020. Five of these events involved a seized A/C compressor. The other two events involved a seized A/C motor and a faulty A/C electronic control unit. None of the reported events resulted in fire.

[6] All OTSI reports are published and can be found on the OTSI website at www.otsi.nsw.gov.au in the bus investigation section.
[7] OTSI Bus Safety Investigation Report, Bus Fires in NSW 2020, available at www.otsi.nsw.gov.au

PART 2 ANALYSIS

Introduction

2.1 The investigation focused principally on the potential factors that may have contributed to the bus fire and identification of safety improvement opportunities.

2.2 As highlighted by the findings of related OTSI investigations and the annual summaries of bus fires in NSW, the securing of bus wiring cables, looms, and harnesses, to prevent movement, chafing or vibration while in service, and regular inspection of electrical wiring, are integral factors in the prevention of thermal events.

Examination of the bus

2.3 The bus was destroyed as a result of intense fire and associated heat.

2.4 The Engine Bay Fire Suppression System (EBFSS) did not activate, as there was no thermal activity/fire in the engine bay.

Fire damaged the EBFSS wiring located within the interior A/C duct running down the offside of the bus, resulting in the driver's FSS alert activation due to both pressure switches in that system having lost electrical continuity.

2.5 Heat and fire signatures, both on the bus exterior (Figure 15) and inside the bus body, showed intense heat and fire damage in the area of the roof-mounted A/C pod, associated M2 node and wiring.

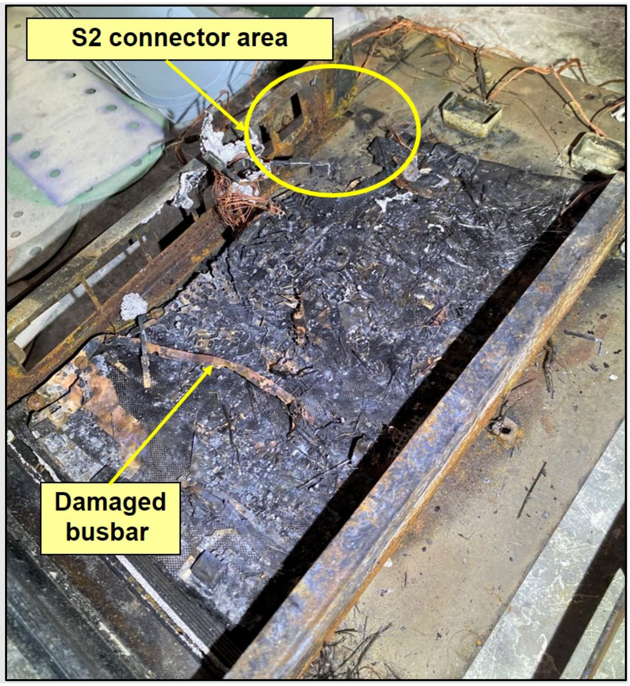
Source: OTSI

Figure 15: MO5103 fire damage on offside

2.6 While it could not be determined from the wreckage if the A/C system was on at the time of the incident, the 150A fuse, in the wiring connection from the A/C system M2 node S2 connector to the positive terminal block of the battery, had blown.[8] There was no damage to the battery set.

2.7 The Thoreb M2 node and steel casing were located post-incident on the bus floor and had sustained extensive fire damage. The area of the S2 connector, and the metal casing covering that region, exhibited evidence of intense heat, with that corner of the node circuit board disintegrated through thermal decomposition (Figure 16) (see Figure 11 for an image of an undamaged M2 node circuit board).

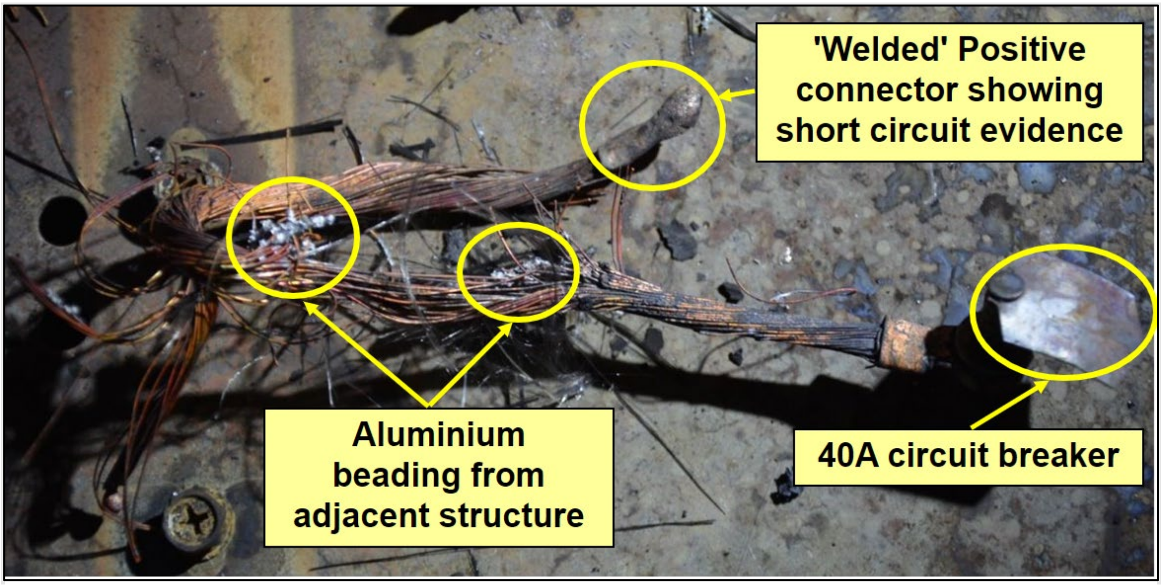
[8] A blown fuse occurs when the power flowing through the circuit overloads the capacity of the fuse which causes the metal ribbon inside the fuse to melt. This results in the power to cease flowing through the circuit.



Source: OTSI

Figure 16: Fire damaged Thoreb M2 Node

2.8 The wiring between a positive connector into the S2 connector and a 40A 12V circuit breaker was identified in the debris. The connector was ‘welded’, showing evidence of a short circuit or high resistance connection (Figure 17). Evidence of aluminium beading from adjacent structures was also present. It was highly unlikely that this came from the steel casing as that was recovered intact. The aluminium cover and heat sinks of the M2 node were destroyed in the fire and only the steel case portions were recovered.



Source: OTSI

Figure 17: S2 connector wiring from M2 Node

2.9 The S2 connector wiring, located in the debris, showed evidence of welding from an electrical short circuit. This indicated that there was an active high amperage power supply to the node at the time of the incident.

Initiation of the fire

2.10 It is highly unlikely that the increased cleaning of TfNSW buses, initiated in response to COVID-19, prior to DENSO's Service Bulletin in September 2020, introduced a contaminate that contributed to the fire in August 2021. The A/C system wiring harness and node, in this configuration, were shielded from direct application of cleaning products, including application via fogging.

2.11 There was the potential that a short circuit between the +B and GND terminals may have occurred, due to decreased insulation resistance between these neighbouring terminals. While the involved S2 connector design was not unusual, the terminals were in close proximity within the polyester housing.

Decreased resistance between the terminals could have occurred due to several factors, including:

- contamination in the connector, such as dust or condensation
- sulphurisation of one of the silver-plated S2 connector tab posts
- the S2 connector was loose
- component deterioration.

2.12 The Thoreb M2 node, configured in the A/C system at the time of the event, was a replacement installed by Thoreb seven years prior. There were no identified failures involving the node since this installation. As such, it is highly unlikely that there was a manufacturing or initial installation fault with this node, due to the period in service without issue.

2.13 While available evidence strongly supports the likelihood that the fire initiated in the S2 connector area of the Thoreb M2 node in the A/C system, there was insufficient evidence available to definitively determine the factor/s that contributed.

As such, several possible scenarios/contributing factors were considered as part of the investigation. These included:

- S2 connector may have been insecure/not fully seated in the terminal
- S2 connector contamination/corrosion
- General contamination (such as dirt, humidity)
- Unidentified wiring abrasion
- Wiring harness compromise/ damage resulting from pinch points in hinged recess access panel arrangement
- Introduced electrical faults in wiring modifications/ repairs/ servicing post-installation
- 40A auto reset circuit breakers may have been unsuitable for the application
- Component failures and/or wiring issues (insecure, abrasions, incorrect wire gauges, missing shake proof washers) introduced by maintenance/repairs.

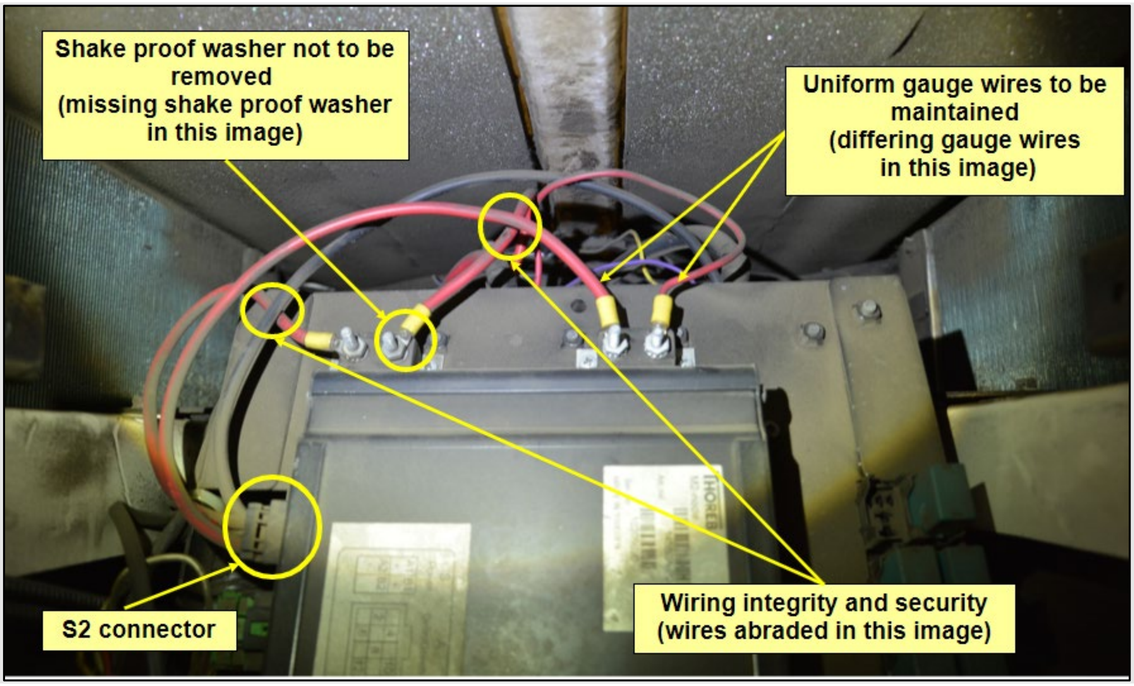
Asset maintenance

2.14 Asset maintenance processes and procedures in operation at the time of the event did not effectively identify faults in similarly configured A/C systems on buses.

At the time of the event, the maintenance regime for the involved A/C system configuration did not effectively identify significant issues present in a high amperage electrical system, or assure that the system was maintained in compliance with the manufacturer's specifications.

2.15 Post-incident inspections of other similarly configured buses within the operator's fleet identified issues with the wiring harness between the main A/C connector blocks, dust contamination, security of terminals and evidence of terminal discolouration within the main S2 connector block.

The M2 node in one inspected vehicle (bus body manufactured in 2012) exhibited several issues, including an incorrect gauge wire, missing shake proof washer, wiring abrasion and dust (Figure 18).



Source: OTSI

Figure 18: Wiring associated with M2 Node within the DENSO A/C system configuration on another bus

2.16 With the durability rating of the S2 connector limited to 25 cycles, this resulted in the S2 connector limited to removal and replacement a maximum of 25 times, in order to meet the requirement of contact resistance.

While inspection of the S2 connector was required, the limit of repeated insertion/removal, in accordance with the manufacturer's specifications, required strict documentation and inspection requirements to ensure appropriate management and replacement regimes of the power source.

2.17 For the period commencing 1 January 2020, the involved bus's A/C system had several faults requiring repair/ replacement parts. There was no data available of failure mode and effects analysis having been conducted.

2.18 The last scheduled maintenance on the bus, which included routine A/C system maintenance and inspection as part of a 'B Service' (conducted every 30,000 km), was 21 days before the incident. This maintenance included a check of the A/C system wiring for rubbing, loose connections and security. However, there were no specifications for the wiring inspection procedure.

2.19 The inspection requirements of the operator's 'B Service' were not effective as they did not specify the inspection requirements or reference a maintenance procedure which complied with, or exceeded, the original equipment manufacturer specifications.

There was no documented requirement for the node to be dropped from the recess for the wiring inspection to be conducted. Without dropping the node, visibility and examination of the wiring harness was limited.

This is supported by the post-incident inspections on similarly configured buses, which specified the dropping of the node from the recess as part of the process, subsequently identifying several issues with A/C system wiring.

2.20 In addition to the standard service inspection limitations, with no reported faults found during the B Service inspection 21 days prior to the incident, there are several possible scenarios:

- no faults existed in the roof-mounted A/C system at the time of inspection. A fault occurred in system in the period between the inspection and the incident
- a fault, such as the S2 connector not being fully seated into the terminal connections, existed at the time of the inspection but was not identified
- there was corrosion in an S2 connector block terminal which was not visible during inspection, requiring the connector to be removed from the M2 node, and terminals inspected, to identify but not conducted as it was not part of the inspection regime

- the node was dropped from the recess for inspection and the wiring inadvertently crushed/compromised in the recess or hinged area, when the drop-down panel was returned to its position following inspection, leading to an electrical short circuit/arcing
- previous A/C system repairs introduced compromised elements to the associated wiring, such as an incorrect gauge of wire, missing shake proof washer or contact between wires, which was not identified.

2.21 There were over 330 buses between seven to 13 years old in Australia, with the same A/C system configuration as the incident bus, with no associated thermal events reported prior to this event.

This signifies a continuous period of reliable operation of this A/C system configuration in buses, indicating that electrical faults may have been introduced into individual buses during A/C system maintenance.

However, the in-service period of this A/C system configuration may also indicate that the lifespan and/or reliability of some system components may have reached or exceeded maximum limits.

2.22 The accessibility design/location of the roof-mounted node, with a hinged action to drop it from the recess, may unintentionally introduce a latent issue of pinch points/insecure wiring/abrasions during maintenance.

Asset management

2.23 The TfNSW BOAS required that only licensed repairers perform safety critical work on buses, with ‘safety critical systems’ identified as brakes, suspension and steering.

There were no specific requirements for licensed auto electricians to routinely inspect bus A/C systems, which were high amperage electrical systems with the potential for significant consequences if a fault occurred, such as a short circuit in a roof-mounted system resulting in an uncontained fire.

BOAS requirements did not effectively address the risks of an electrical fault in a bus high amperage electrical system, such as an A/C system, requiring more effective inspection processes and specialist technician licensing requirements.

In comparison, the Victorian Maintenance Management System, for accredited bus operators, provided a more comprehensive regulatory and safety management framework, with vehicle manufacturer's specifications, a national heavy vehicle inspection manual, and any applicable legislation or vehicle standards, to be used in the development and maintenance of inspection checklists and for defect identification.

2.24 The post incident A/C system inspections, conducted on similarly configured buses, identified significant issues, including non-compliant gauge wiring, wiring abrasions, and missing fasteners, with some buses containing several issues.

It could not be determined if these issues were introduced by licensed automotive repairers, who were not licensed auto electricians. However, the likelihood of non-compliant repairs and maintenance in this configuration of A/C system may be considerably reduced if maintained by licensed auto electricians, who install, maintain, identify faults, and repair electrical wiring and computer-based equipment in motor vehicles.

2.25 In consideration that the bus A/C system configuration was a high amperage electrical system, with the potential for a significant thermal event if components were degraded, including wiring abrasions and node power connector contamination, there is an opportunity for the operator and asset owner to review licensing requirements for technicians inspecting and maintaining these systems. This is to ensure that technicians conducting inspections and maintenance have the appropriate skills and knowledge to maintain a safe high amperage electrical system on a bus.

2.26 Critical design decisions relating to high current circuits, including conductor decisions and circuit breaker selections, should be clearly documented and available to the maintainer.

In addition, Failure Modes and Effects Analysis should be conducted and available in relation to high current circuits, as the potential consequences of failure modes are risk to life and/or loss of the asset.

2.27 The TfNSW BOAS audit programs, in place at the time of the event, did not effectively support the identification and rectification of faults in the involved A/C system configuration.

The BOAS Independent Audits included a requirement to review the operator's maintenance program to ensure it was 'consistent or better than the manufacturer's specifications'. However, the identification of significant electrical issues in similarly configured buses, post incident, including wire chaffing, incorrect gauge wires and missing shake proof washers, does not support that this requirement was effectively applied.

2.28 In this incident, the bus operator's determination that their drivers were not to isolate the bus battery set, due to identified risks, was strongly supported. The investigation identified that the main battery isolation switch for this bus configuration could not be safely accessed.

The battery isolation switch was located under a panel on the offside of the bus, adjacent to an active traffic lane. To access the switch in this event, the driver would have been required to enter an active traffic lane, in reduced visibility due to smoke, exposing the driver to potential injury through collision with a vehicle, in addition to close proximity to an intense bus fire.

Safety action reported by TfNSW in March 2021 (see *Safety actions taken*), once implemented, should adequately address battery isolation functionality safety issues.

2.29 Although the AMB Standard '*Mounting and Installation of Electrical Equipment'* did not apply to the involved asset, this highlighted that there was an expectation about what should have occurred for maintenance standards for in-service assets not subject to the Standard. There was a reported reliance on the operator to ensure compliance.

There is an opportunity for TfNSW to consider reviewing current asset management requirements, to apply a more comprehensive safety risk management and regulatory framework.

Safety actions taken

2.30 Both DENSO and the bus operator initiated comprehensive engineering inspections of the A/C systems of similarly configured buses, immediately after the incident. DENSO identified several wiring issues during these inspections and subsequently made recommendations for rectification to the bus operator as part of this process.

All identified wiring issues were rectified during this process.

2.31 On 5 November 2021, OTSI published a Bus Safety Advisory '*Risk of air conditioning system electrical fires on buses*' (*Appendix 2: OTSI Safety Advisory*).[9]

The key points for operators were to assess the risks (as per their Safety Management System) relative to their specific fleet, to ensure that controls were in place to minimise the risk of electrical fires.

The following actions were documented for consideration for all model buses configured with a DENSO A/C system controlled by a Thoreb M2 programmable node:

- Inspect cabling associated with the Thoreb M2 node and ensure wiring is undamaged and secured correctly with adequate clearance of any possible points of contact.
- Inspect the S2 connector block terminals for discolouration, any evidence of heat damage and ingress of contaminants.
- Review maintenance regimes to ensure inspections adequately address and remedy any issues with wiring integrity (including checking shake proof washers have not been removed), security and overall cleanliness of the A/C system.

2.32 On 7 March 2022, following a Directly Involved Party review of the draft report for OTSI investigation *Bus Fire 2001ST, Glebe, 11 January 2021*,[10] TfNSW reported safety actions that included the following:

[9] OTSI Bus Safety Advisory, *Risk of air conditioning system electrical fires on buses*, available at www.otsi.nsw.gov.au
[10] Final report available at www.otsi.nsw.gov.au

- Review the current bus battery isolation requirement, with compliance with the T BU FL 01701 ST Mounting and Installation of Electrical Equipment Standard, Version 1.0, Issue date: 3 April 2019.
- Review alternative safe work practices of power isolation to the vehicle in the event of a thermal/fire occurrence.
- Review all relevant emergency procedures and current training programs undertaken for bus fires and thermal events.
- Risk assess the flammability and combustibility of materials used to manufacture bus bodies. Record and document the identified controls to consider options to incorporate into the current Divisions' risk mitigation strategies.

2.33 As part of the Directly Involved Parties review process for the Draft Report, TfNSW advised that the Health and Safety Assurance team, within TfNSW Health and Safety, would incorporate any additional feedback outlined in the OTSI Final Investigation Report. In addition, that team would undertake an internal safety assurance activity, inclusive of relevant internal TfNSW stakeholders, including Public Transport Contracts and Partnerships, and Asset Management and Regulatory Operations , within 12 to 18 months of publication of the OTSI report.

PART 3 FINDINGS

From the evidence available, the following findings are made with respect to the bus fire involving MAN Automotive (Australia) Pty Ltd model 18.320, fitted with a Custom Coaches CB80 body, registration MO5103, which occurred in Campbelltown, NSW on 16 August 2021.

Contributory Factors

3.1 Electrical arcing in the vicinity of the air conditioning system Thoreb M2 control node, specifically in the region of the main S2 connector block and its associated wiring harness, escalated to fire.

Other Safety Factors

3.2 The driver effectively managed the thermal event in proceeding to an appropriate location for the safe evacuation of passengers, with reduced potential for injury to bystanders and damage to infrastructure, and the directed evacuation.

3.3 The operator's maintenance program for the involved air conditioning system configuration did not effectively identify significant issues present in a high amperage electrical system, or assure that the system was maintained in compliance with the manufacturer's specifications.

3.4 Design decision documentation for the involved air conditioning system configuration, including node programming and circuit breaker selection, was not available to the operator/maintainer of the asset.

3.5 The Transport for NSW Bus Operator Accreditation Scheme audit program did not effectively assure that the operator's maintenance regime, for a high amperage electrical system, was consistent with or exceeded the original equipment manufacturer's recommended maintenance standards.

3.6 The Transport for NSW asset maintenance requirements, for buses acquired from 2019 onwards, did not effectively address the risks of an electrical fault in a bus high amperage electrical system, such as an air conditioning system, requiring more effective inspection processes and specialist technician licensing requirements.

PART 4 RECOMMENDATIONS

Noting that some remedial safety action has already been implemented, it is recommended that the following additional safety actions be undertaken by the specified responsible entity.

Bus and coach operators

4.1 Review maintenance regimes to ensure inspections adequately address and remedy any issues with wiring integrity (including checking that shake proof washers have not been removed), security and overall cleanliness of the air conditioning system.

4.2 For operators of all model buses configured with a DENSO air conditioning system, controlled by a programable Thoreb M2 node, ensure that the manufacturer specifications for contact resistance limitations of the Tyco S2 connector, for a maximum of 25 removal/replacement cycles, be incorporated into asset management and maintenance regimes.

Transport for NSW

4.3 Consider reviewing the framework for asset systems configurations, to ensure that critical design decisions related to high current systems, including Failure Mode Effect and Analysis, are documented and available to operators and maintainers.

4.4 Consider reviewing current asset management requirements to apply a more comprehensive safety risk management and regulatory framework, for long-term asset management.

PART 5 APPENDICES

Appendix 1: Sources, Submissions and Acknowledgements

Sources of Information

- Busabout
- DENSO Automotive Systems Australia Pty Ltd
- Thoreb
- Transport for NSW

References

National Fire Protection Association, NFPA 921 *Guide for Fire and Explosion Investigations*, 2021 Edition, United States of America

DeHaan, J., & Icove, D. (2012). Kirk's Fire Investigation. New Jersey Prentice Hall

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:

- Busabout
- Custom Bus Group Pty Ltd
- DENSO Automotive Systems Australia Pty Ltd
- Thoreb
- Transport for NSW.

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, an explanation for doing so was provided.

Appendix 2: OTSI Safety Advisory

SAFETY ADVISORY

Office of Transport Safety Investigations

Risk of air conditioning system electrical fires on buses

The incident

The Office of Transport Safety Investigations (OTSI) recently conducted a preliminary investigation into a bus fire at Macarthur Square on 16 August 2021. The bus operated by Busabout was severely damaged by fire, likely the result of an electrical fault within the air-conditioning (A/C) system.

The bus was a MAN 18-320 model fitted with a CB80 Custom Coaches body manufactured in June 2012. The A/C system on the bus was manufactured by DENSO Automotive Systems Australia and controlled by a Thoreb M2 programmable node.

Preliminary investigations found damage associated with electrical arcing in the vicinity of the A/C Thoreb M2 control node, specifically in the region of the main S2 connector block and its associated wiring harness.

Inspections of other similarly configured buses, within the Busabout fleet, indicated issues with the wiring harness between the main A/C connector blocks, security of terminals and evidence of terminal discolouration within the main S2 connector block.

Key points for operators

Assess the risks (as per your Safety Management System) relative to your specific fleet, to ensure that controls are in place to minimise the risk of electrical fires. The following actions should be considered for all model buses configured with a DENSO A/C system controlled by a Thoreb M2 programmable node:

- Inspect cabling associated with the Thoreb M2 node and ensure wiring is undamaged and secured correctly with adequate clearance of any possible points of contact (*refer to Figure 1 and Figure 2*).
- Inspect the S2 connector block terminals for discolouration, any evidence of heat damage and ingress of contaminants.
- Review maintenance regimes to ensure inspections adequately address and remedy any issues with wiring integrity (including checking shake proof washers have not been removed), security and overall cleanliness of the A/C system.

Safety message

The findings of the preliminary investigation highlight the importance of effective maintenance of critical high amperage electrical systems.

For further information contact: Transport.Safety@otsi.nsw.gov.au

w: otsi.nsw.gov.au e: transport.safety@otsi.nsw.gov.au OTSI REF: I02009 05 November 2021

SAFETY ADVISORY

Office of Transport Safety Investigations

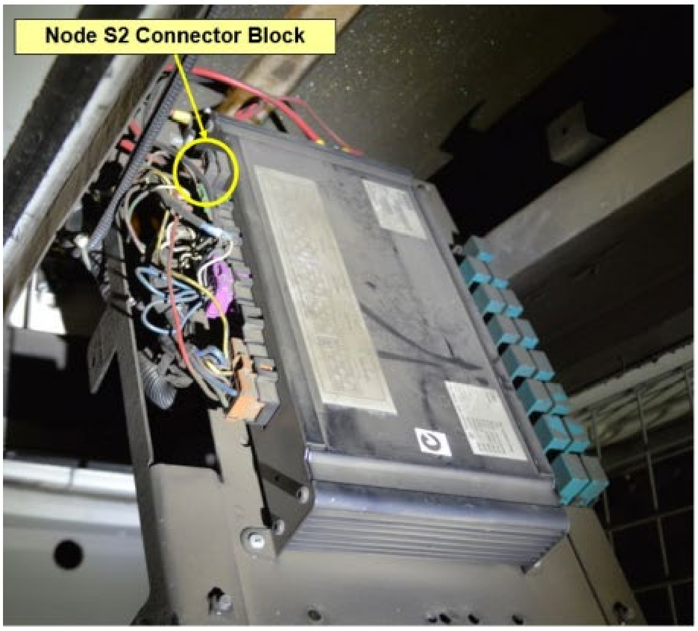


Figure 1: Location of Thoreb M2 Node and S2 connector block in A/C system

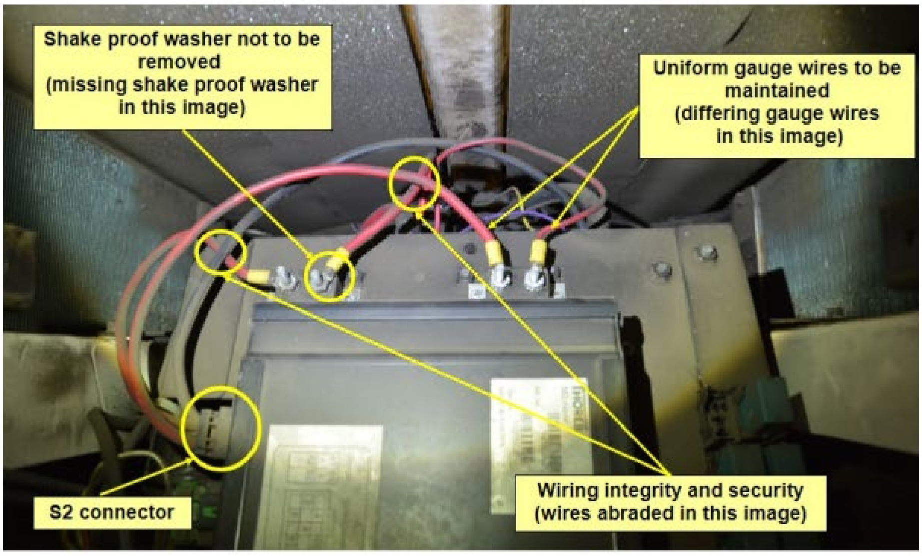


Figure 2: Wiring associated with M2 Node within the DENSO A/C system configuration

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