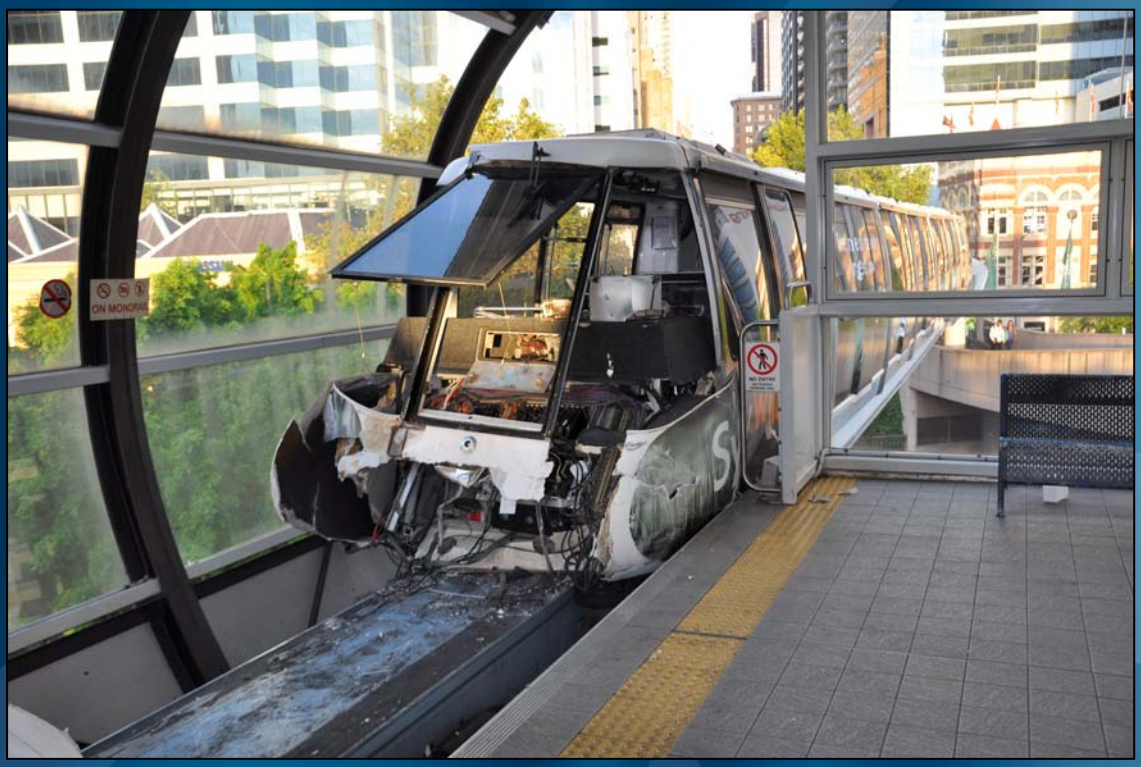
OTSI Office of Transport Safety Investigations

RAIL SAFETY INVESTIGATION REPORT



MONORAIL COLLISION

DARLING PARK

27 FEBRUARY 2010

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Released under the provisions of
Section 45C (2) of the *Transport Administration Act 1988* and
Section 67 (2) of the *Rail Safety Act 2008*

Investigation Reference 04471

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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 accidents and incidents in the rail, bus and ferry industries. OTSI investigations are independent of regulatory, operator or other external entities.

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

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

OTSI cannot compel any party to implement its recommendations and its investigative responsibilities do not extend to overseeing the implementation of recommendations it makes in its investigation reports. However, OTSI takes a close interest in the extent to which its recommendations have been accepted and acted upon. In addition, a mechanism exists through which OTSI is provided with formal advice by the Independent Transport Safety Regulator (ITSR) in relation to the status of actions taken by those parties to whom its recommendations are directed.

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ACRONYMS AND ABBREVIATIONS

ACC	Anti-Collision Control (system)
ACES	Anti-Collision Emergency Stop (system) - replaced by the ACC
ITSR	Independent Transport Safety Regulator (prior to 1 July 2010 it was the Independent Transport Safety and Reliability Regulator or ITSRR). Throughout the report the new name and the acronym ITSR are used.
OTSI	Office of Transport Safety Investigations
SCADA	Supervisory Control and Data Acquisition (system)

GLOSSARY OF TERMS

AutoPilot	The monorail vehicle control system. The AutoPilot provides information as to the distance of a vehicle ahead and this information is used by the Programmable Logic Controller (PLC) as part of the ACES system.
ACES System	An additional safety circuit added to the monorail control system in 2007 to provide a backup when the monorail is operating in manual mode. An audible alarm is activated inside the driver's cab when another monorail is detected 150m ahead. If the distance closes to 100m, a second two tone alarm sounds and the emergency brakes are activated automatically.
Diode Loop	An electronic circuit running on the side of the monorail beam which has diodes at a set distance apart. These diodes assist the monorail control system in determining the distance between it and the monorail ahead.
Interface Agreement	An agreement in writing between two parties concerning the management of identified safety issues requiring negotiation between the parties.
Programmable Logic Controller (PLC)	Part of the monorail control system. In manual mode the initiation of the ACES system (alarm and stopping function) is controlled by the PLC.
Regenerative braking	The action of the DC motor assisting in slowing the vehicle; the motor windings being reversed by the drive thus providing braking rather than propulsion. During Manual operation this braking is normally controlled by a Key Switch, which is turned to Neutral, or by using the Speed Control Potentiometer. However, if the Emergency Stop Button or the ACES is activated, the regenerative braking is also activated for 0.5 seconds along with the mechanical braking system.
SCADA system	A computer system that allows the controller in the Monorail Control Centre to view the performance and position of monorails in real time around the track.

EXECUTIVE SUMMARY

At about 4:00pm[1] on Saturday 27 February 2010, a Veolia Transport Sydney Metro monorail (Monorail 1) carrying 15 passengers collided with the rear of a stationary monorail (Monorail 4) at Darling Park Station, Darling Harbour, Sydney. Monorail 4 had 45 passengers on board and was experiencing door problems which caused it to stand at the Darling Park Station for longer than normal. It had just completed loading passengers and the doors on five carriages were still in the open position when it was hit from behind by Monorail 1 which at the time of impact was estimated to be travelling at 6m/s (22km/h). Four passengers from Monorail 1 sustained minor injuries and three were transported to hospital for treatment. No one on Monorail 4 was injured.

Each monorail is fitted with an Anti-Collision Emergency Stop (ACES) system which is interfaced to the main Programmable Logic Controller (PLC). This control system acts as a backup when the monorail is being operated in manual mode. An alarm is activated inside the driver's cab when it detects another monorail 150m ahead and a different alarm and the emergency brakes are activated when the separation closes to 100m. On this occasion the alarms and emergency brakes activated correctly but did not stop the monorail before it struck the stationary monorail in Darling Park Station.

The investigation established that Monorail 1 was travelling above the speed profile at the time of the collision and that the Driver did not react quickly enough to brake the monorail when the first of two alarms sounded, warning him of the presence of another monorail 150m ahead. The Driver had about five seconds after the first alarm sounded during which time he should have applied the brakes before the emergency brakes activated. In this five second interval, the Driver received a two-way radio call from Train Control warning him of the stationary monorail ahead. It is likely that this call distracted him sufficiently to degrade his braking reaction time. The speed profile for the section of track where the alarm activated was 8.5m/s (31km/h) and testing showed that the most likely scenario was that Monorail 1 was travelling at around 9.5m/s (34km/h) in that section.

[1] All times referred to in this report are Australian Eastern Daylight Time.

In the course of the investigation, monorail speed, driver distraction, control system function, tree obscuration, loss of data communication and infrastructure maintenance were all identified as issues.

Prior to the collision, Veolia had planned a number of major upgrades to the monorail drive system, the monorail control system and the control room. At the time of the collision, the control system on Monorail 2 had been upgraded. Upgrades to the other monorails have been progressively phased in since the collision. Veolia has also made changes to departure notification procedures from Galeries Victoria Station and installed CCTV at stations and in the driver's cab of each monorail.

To improve the safety of its operations further, it is recommended that Veolia:

- ensures that its drivers comply with the prescribed operating speeds for all sections of the track;
- ensures that its drivers understand the emergency braking system and are practised in its operation in periodic training drills;
- verifies that the new Anti-Collision Control system ensures sufficient separation between monorails and does so under all operating conditions;
- finalises arrangements with the responsible authorities for the pruning or removal of vegetation which obscures track visibility within the "rail corridor", particularly the tree presently obscuring sighting of the entrance into Darling Park Station from the City Centre Station approach;
- ensures its track tape maintenance schedule provides for the timely inspection and replacement of worn tape;
- upgrades the audio recording system used for voice recordings between train control and drivers to ensure ease of retrieval and clear, high fidelity replay; and
- ensures the monorail management system is capable of providing controllers with real-time data on the location of all monorails on the track.

Full details of the Findings and all of the Recommendations of this investigation are contained in Parts 4 and 5 respectively.

PART 1 CIRCUMSTANCES OF THE COLLISION

Incident Synopsis

1.1 At about 4:00pm on Saturday 27 February 2010, a Veolia Monorail, Monorail 1, operating on the Sydney Metro Monorail system, collided with the rear of Monorail 4 which was stationary at Darling Park Station (see *Photo 1*). The doors on Monorail 4 had malfunctioned causing it to stand at the station for longer than its normal dwell time. As Monorail 1 approached Darling Park, it was travelling above the speed profile and the Driver, unaware that the monorail ahead had stopped, did not react quickly enough to brake his monorail before the backup Anti-Collision Emergency Stop (ACES) system activated. The ACES system on Monorail 1 was not effective in stopping the monorail before it impacted with Monorail 4. As a result of the collision three passengers from Monorail 1 were injured and transported to hospital and another passenger claimed to have sustained an arm injury. No one on Monorail 4 was injured.

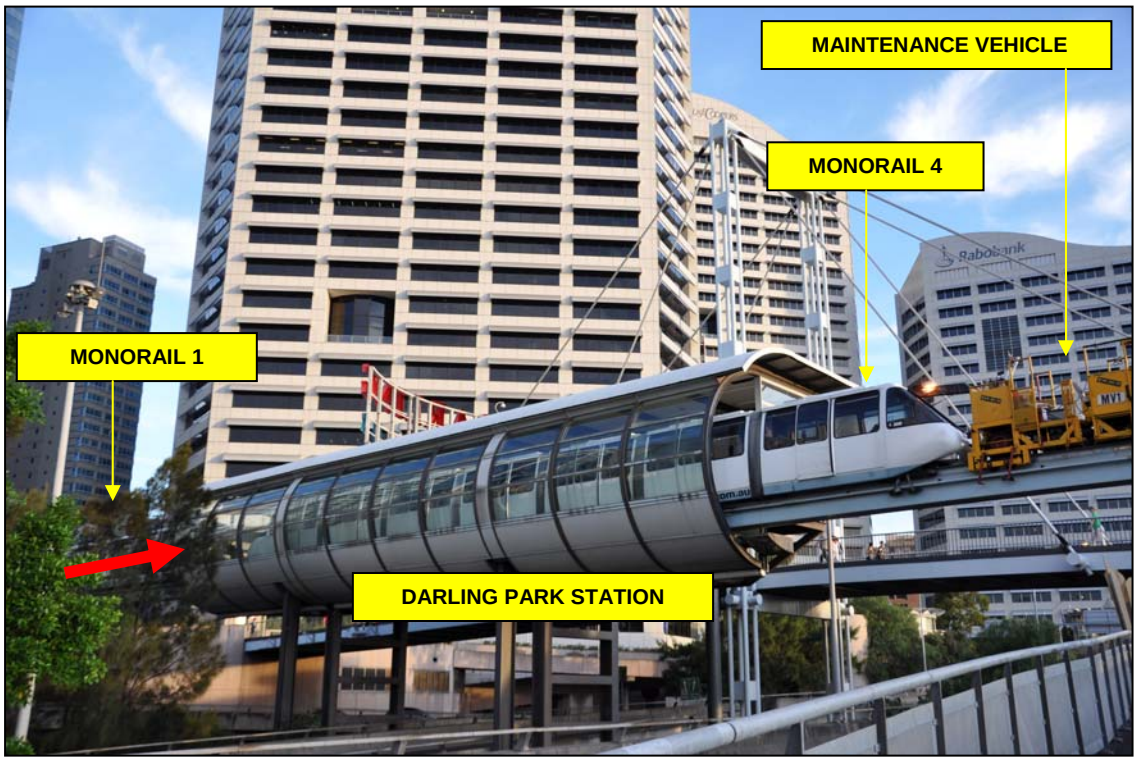

Photo 1: Darling Park Station after the collision

Location

1.2 Darling Park Station is located in Sydney's CBD on the Eastern side of Darling Harbour (see *Figure 1*). The station at Darling Park, like all the other monorail stations, is elevated. It is accessed via an overhead walkway from Market Street near the Pyrmont Bridge. The Pyrmont Bridge is a pedestrian connection between the Eastern and Western sides of Darling Harbour.

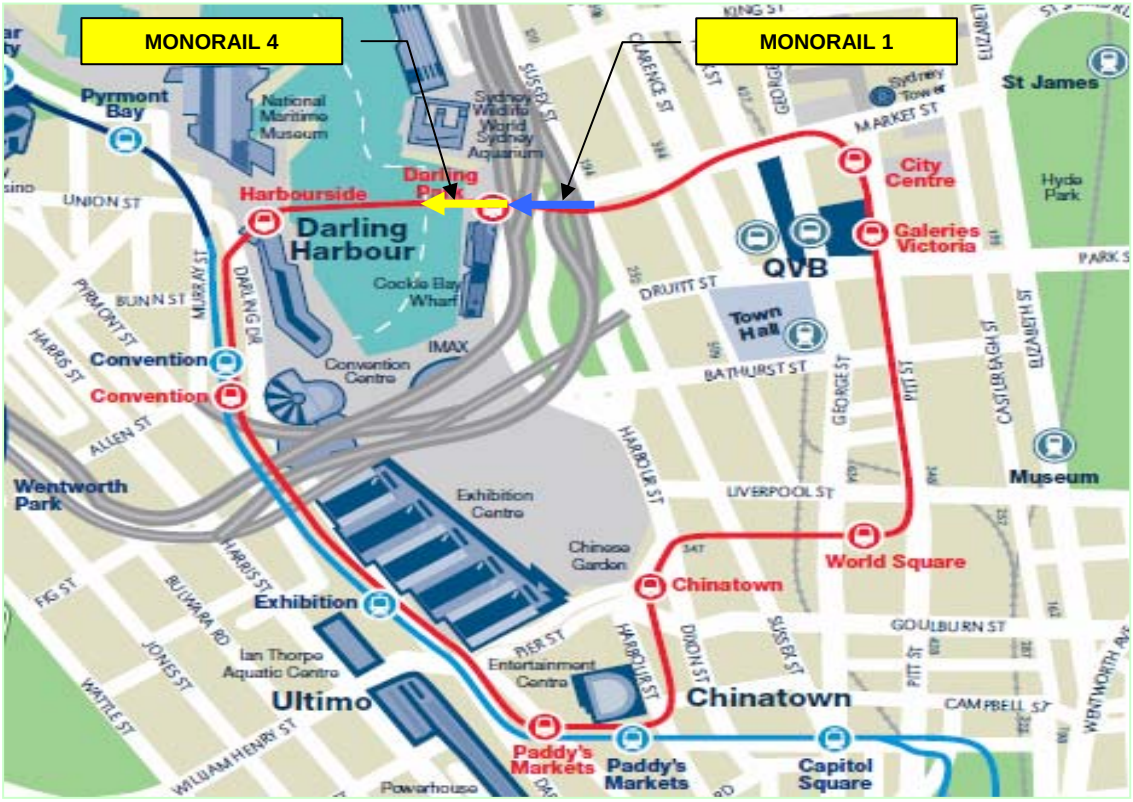

Figure 1: Monorail Track Diagram

Before the Collision

1.3 Four monorails were operating on the day of the collision. Monorail 1 was the first to commence operations at 6:42am, initially as a freight vehicle carrying supplies to all monorail stations before switching to passenger services at approximately 7:00am. Monorail 6 commenced operating at 6:57am and Monorail 4 at 7:50am. Monorail 2 was brought into service at 9:28am as a replacement for Monorail 1 which was taken out of service at 9:34am due to problems with its drive units. Monorail 1 was returned to service at 11:10am with four of its six drive units in operation.[2] The four monorails then operated throughout the day until the time of the collision.

[2] A monorail is permitted to operate with up to three of its drive units cut out.

1.4 The Driver of Monorail 1 commenced duties at 1:00pm when he signed on at Paddy's Market Station. He started his shift driving Monorail 4 but at about 3:45pm was told by the Controller to swap to Monorail 1. Monorail 4 was to be taken out of service as its recurring door problems were slowing down the system. Throughout the day Monorail 1 was operated in manual mode which requires drivers to manually control speed and dwell time at stations.

1.5 Shortly before the collision, at Galeries Victoria Station, a Relief Driver boarded Monorail 1 with the intention of relieving the Driver at World Square Station for his scheduled break. At the next station, City Centre Station, Monorail 1 stopped for about 45 seconds to set down and pick up passengers. Monorail 1 then departed the station and, according to the Driver, accelerated to normal speed.

1.6 Meanwhile, at Darling Park Station, Monorail 4 was experiencing problems closing its doors and its Driver reported this to the Controller by radio. After Monorail 1 departed City Centre Station, the Controller realised he should contact the Driver of Monorail 1 and warn him about the stationary Monorail 4 ahead. However, the Controller did not know the exact position of Monorail 1 as the monorail was not shown to be moving on his supervisory control and data acquisition (SCADA) system.

1.7 The Controller called Monorail 1 but his call went unanswered. He then called again, this time contacting the Driver, and advised him that Monorail 4 was stationary at Darling Park Station.

1.8 On the recording of this call at 3.59pm, an in-cab alarm can be heard sounding in the background while the call is in progress. This alarm warns drivers that they are within 150m of another monorail. At 100m, a second alarm can be heard to activate which also corresponds with the emergency braking system engaging automatically.

1.9 Had the Driver of Monorail 1 been able to see Darling Park Station as he approached it, he may have been able to initiate timely braking action. However, there is a large tree located approximately 40m before the entrance to Darling Park Station (see *Photo 2*). The Driver of Monorail 1 stated that until he drew alongside it, the tree obscured his visibility of the station. He stated that, when he passed the tree, he reacted by activating the emergency stop button and turning the monorail speed switch to zero. Both the Driver

and Relief Driver said that they felt no braking effect and that the monorail entered Darling Park Station at about 6m/s.

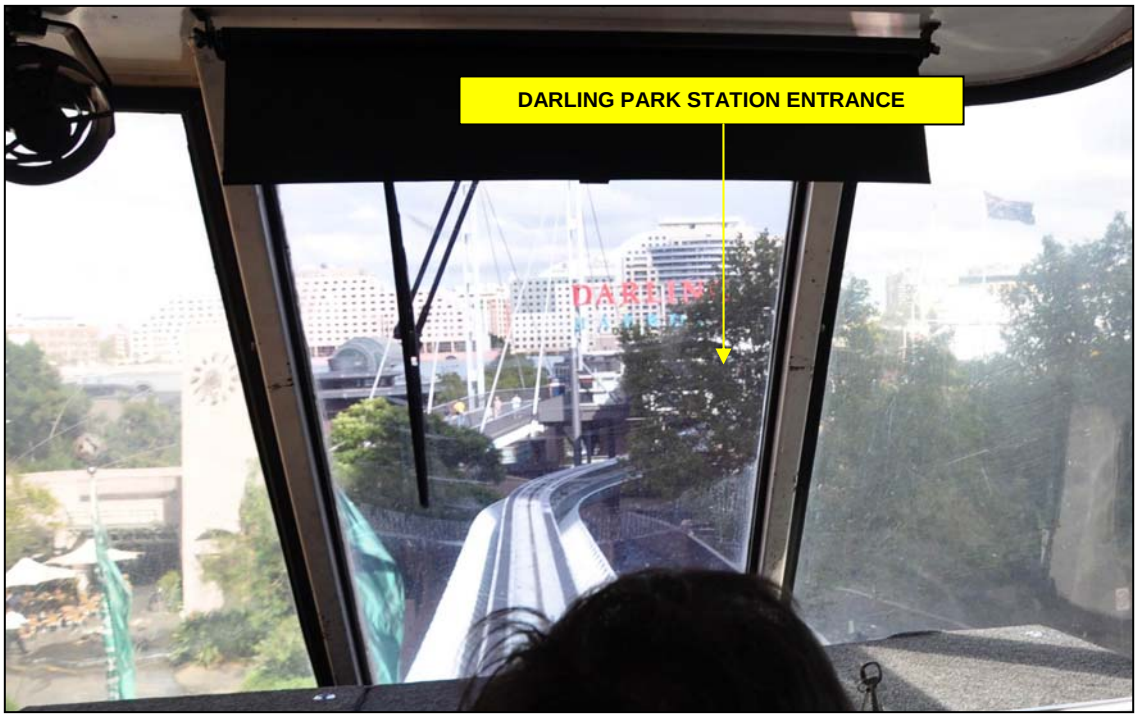

Photo 2: View from monorail approaching Darling Park Station

The Collision

1.10 Despite the Driver's actions and the activation of the ACES system, Monorail 1 entered the station precinct, collided with Monorail 4 and shunted it forward about three metres. The doors on five carriages of Monorail 4 were still in the open position at the time of impact. There were 45 passengers on board Monorail 4 and 15 passengers on Monorail 1.

1.11 When the impact occurred, the Darling Park Station Supervisor, who was assisting with the door problem, was halfway inside the driver's cab of Monorail 4 and managed to reach and hit the emergency stop button as Monorail 4 was propelled forward. The Driver of Monorail 4, who was standing at the time of the impact, was thrown backwards to the floor.

1.12 The Driver of Monorail 1, who was seated at the time of the impact, was thrown against the dashboard and then to the floor. The Relief Driver who was standing behind the Driver managed to brace himself before the impact.

After the Collision

1.13 The Relief Driver in Monorail 1 used a portable radio to inform the Controller of the collision. Not realising Monorail 4 had been hit from behind, the Station Supervisor called the Controller to tell him she thought the Monorail had surged and that the Driver was on the floor. She was told by the Controller to standby. The Controller was able to see on the Darling Park Station CCTV that Monorail 1 was mostly outside the station. He directed the Relief Driver to climb back through the monorail to check on the passengers and then dialled 000 to contact emergency services. He then called station staff at Darling Park Station and directed them to assist in evacuating passengers.

Photo 3: Emergency access window between monorail carriages

1.14 NSW Police received notification of the collision at 4:07pm and arrived at the scene at 4:19pm. Passengers on Monorail 1 were evacuated by the Police Rescue Unit through the emergency access windows between carriages to the front of the monorail (see *Photo 3*). Here they were assisted through the front window of the driver's cab onto the platform.

1.15 NSW Ambulance was notified of the collision at 4:10pm with the first unit arriving on the scene at 4:27pm. Four passengers on Monorail 1 were injured.

An 86-year-old woman sustained lacerations and bruising after falling off her seat to the floor. She was placed on a stretcher and was passed through the emergency access windows to be evacuated from the Monorail. A 26-year-old woman hurt her elbow after falling from a standing position. A 3-year-old boy was thrown from his seat to the other side of the monorail where he struck his head and sustained a laceration to his eyelid. These three passengers were transported to nearby hospitals. Another female passenger on Monorail 1, an English tourist, reported that she sustained an arm injury as a result of the collision but could not wait for treatment due to travel commitments. No staff members or passengers on Monorail 4 were injured.

1.16 The collision caused significant damage to the front of Monorail 1 (see *Cover Photo)* and the rear of Monorail 4 (see *Photo 4*). Monorail 1 was damaged to the extent that it could not be moved under its own power. It was later towed back to the monorail maintenance facility by the maintenance vehicle.

Photo 4: Collision damage to Monorail 4

1.17 Although Monorail 4 was propelled about three metres past the end of the platform as a result of the impact, the passengers were all able to exit directly onto the platform. However, two carriage doors which failed to open had to be manually opened by another Station Supervisor. The Driver and Station

Supervisor in the cab had to open the emergency access window and climb through to the carriage behind in order to reach the platform.

1.18 The Controller notified the General Manager of Veolia at 4:15pm who directed other members of the management team to attend and assist with the response, assessment and clean-up.

1.19 Some two hours after the collision, ITSR's Duty Officer was notified of the collision by Veolia. ITSR's Duty Officer then notified an ITSR Manager who, in turn, contacted the OTSI Duty Officer. An OTSI Investigator attended Darling Park and conducted an initial inspection of the scene.

1.20 The Drivers of Monorail 1 and 4, the Relief Driver and the Controller were tested for drugs and alcohol after the collision and each returned a negative result.

1.21 After emergency services had completed their duties and the site cleared of passengers, Darling Park Station was then locked down and maintenance staff started recovery operations. At around midnight Monorail 1 and Monorail 4 were towed back to the maintenance facility and the monorail track was inspected for damage, but none was found. Monorail operations recommenced at 8.00am the following day with a normal number of services.

Monorail Information

1.22 **Monorail History and Ownership.** Sydney's monorail commenced operation in 1988 as the Darling Harbour Monorail System, part of the redevelopment of the Darling Harbour area. It is one of three monorail systems operating in Australia; the other two are in Queensland, one on the Gold Coast at Sea World, which also opened in 1988, and the other at Broadbeach, which opened in 1989. All three Australian monorails were built by the Swiss company, Von Roll Transport Systems. The Sydney monorail system was renamed Metro Monorail in 1998 and is currently owned by Metro Transport Sydney Pty Ltd. The day-to-day operations are contracted out to Veolia Transport Sydney Pty Ltd.

1.23 **Monorail Size and Scope of Operations.** The monorail is a continuous 3.6km loop service which runs around Darling Harbour, Chinatown and Sydney's CBD (see *Figure 1*). Operating hours are from 7am to 10pm Monday to Saturday and from 8am to 10pm on Sunday. It operates every day

except Christmas Day. Each monorail takes about 12 minutes to complete a circuit. There is no timetable but, with four monorails operating, the wait between services is usually only a few minutes.

1.24 The monorail service is the third largest commercial passenger rolling stock service in NSW (by passenger journeys). In 2008-2009 it completed over 2.7 million passenger journeys. Six monorails commenced operation in 1988 and, at the time of the collision, four monorails were operational.

1.25 Each monorail can carry a maximum of 72 passengers, with seating for 48. Each monorail is operated by a driver from the front carriage and passengers are generally not permitted to ride in this carriage.

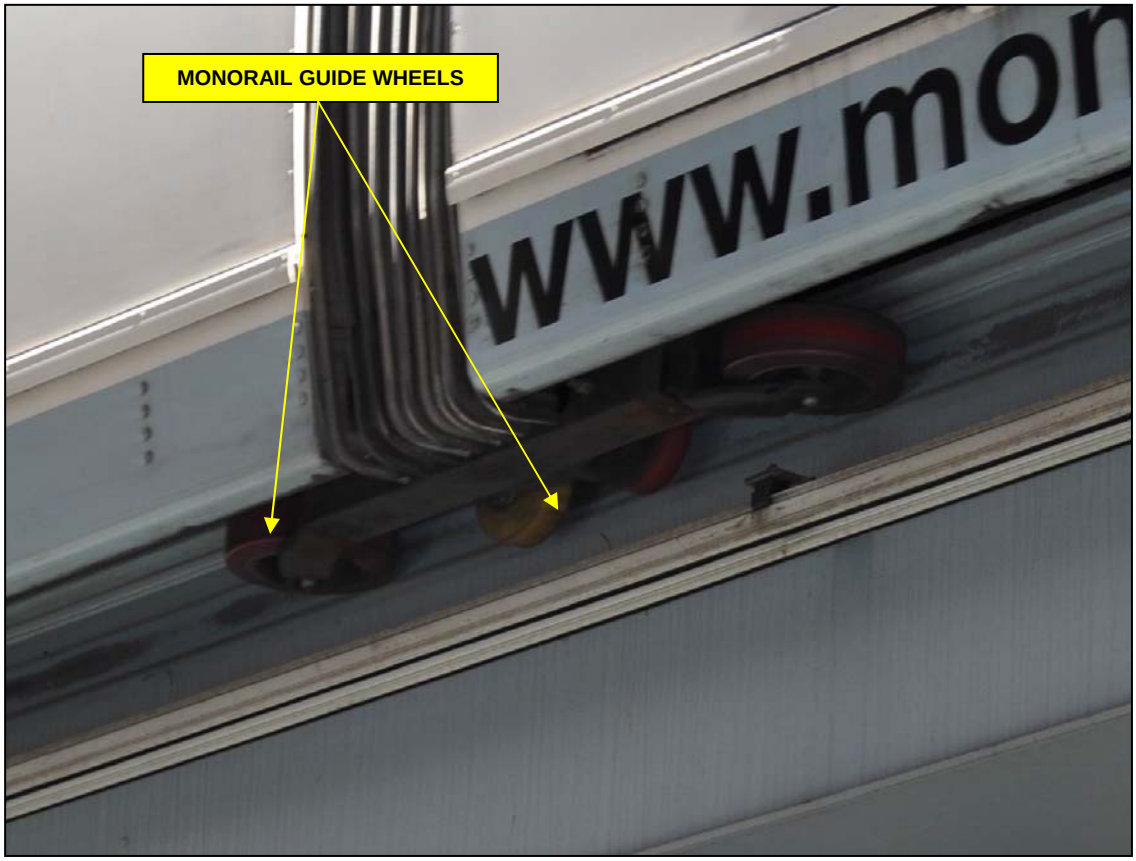

Photo 5: Monorail guide wheels

1.26 **Monorail Technical Specifications.** Each seven-car monorail is powered by six 37kW, 525V DC electric motors located above the drive wheels. These motors also provide a regenerative braking system which can co-act with the monorail's mechanical braking system. Each monorail has six sets of two drive wheels which are fitted with pneumatic heavy-duty rubber tyres. The drive wheels run atop a 940mm wide steel beam fitted with grip tape to increase traction and adhesion. The monorail is guided along the beam by

sets of guide wheels which are located underneath the drive wheels and also at each end of the monorail (see *Photo 5*). Each monorail measures approximately 2.6m high, 2m wide and 32m in length. It has a rated maximum speed of 9.16m/s.

1.27 **Monorail Beam.** The steel box-girder beam is approximately 5.5m above road level and generally follows the contours of the road. The track is supported by vertical steel columns spaced between 20m and 40m apart. A 525V AC power supply is provided along one side of the beam and a control electrical return and diode rail runs along the other side.

1.28 Between City Centre and Darling Park Stations the beam travels to the North side of Market Street then changes back to the South side. On approach to Darling Park Station the beam has a downhill gradient of 6.5%, reducing to 5.5%, and levelling off as it enters the station. The 6.5% section is the steepest grade in the monorail system.

1.29 **Monorail Control Room.** The operation of the monorail system is controlled from a control room located above the maintenance facility. A control panel operator oversees the operation of the system via a computer mimic panel also known as a SCADA (see *Photo 6*). This shows the real time position of each monorail. The control panel operator is able to contact each monorail via two-way radio.

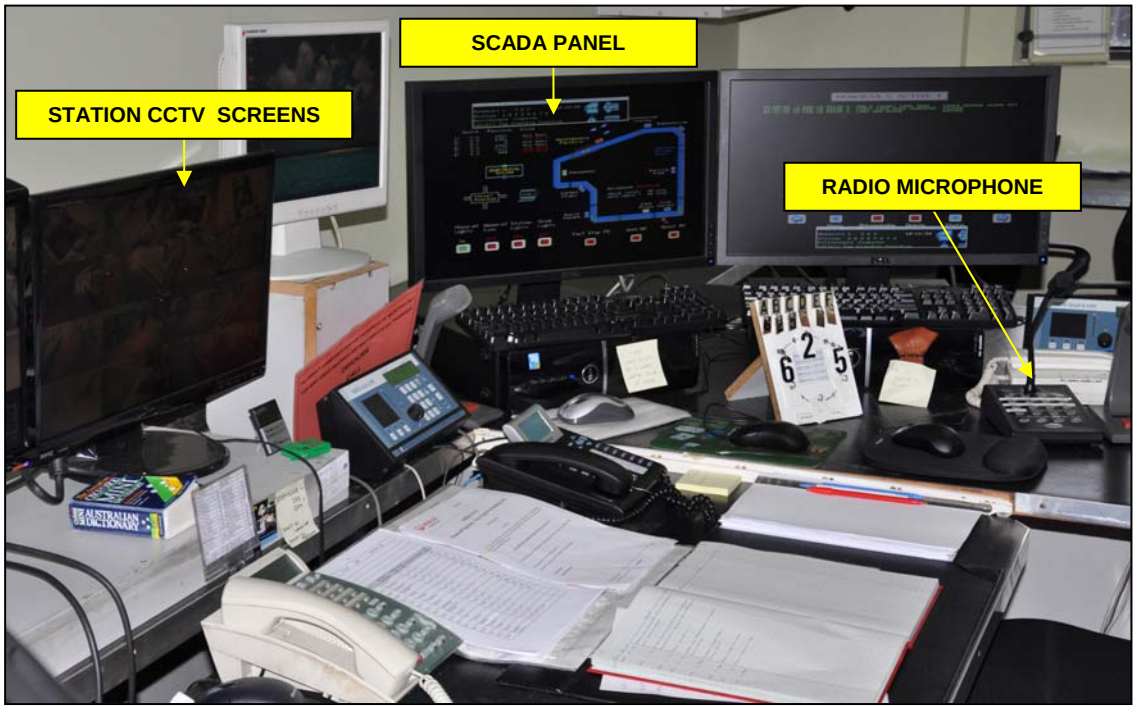

Photo 6: Monorail control area

1.30 **Monorail Stations.** There are eight monorail stations: Harbourside, Convention, Paddy's Market, Chinatown, World Square, Galeries Victoria, City Centre and Darling Park. The maintenance facility is located between Convention and Paddy's Market stations. Monorails are moved on and off the track at the facility via a traverser (see *Photo 7*).

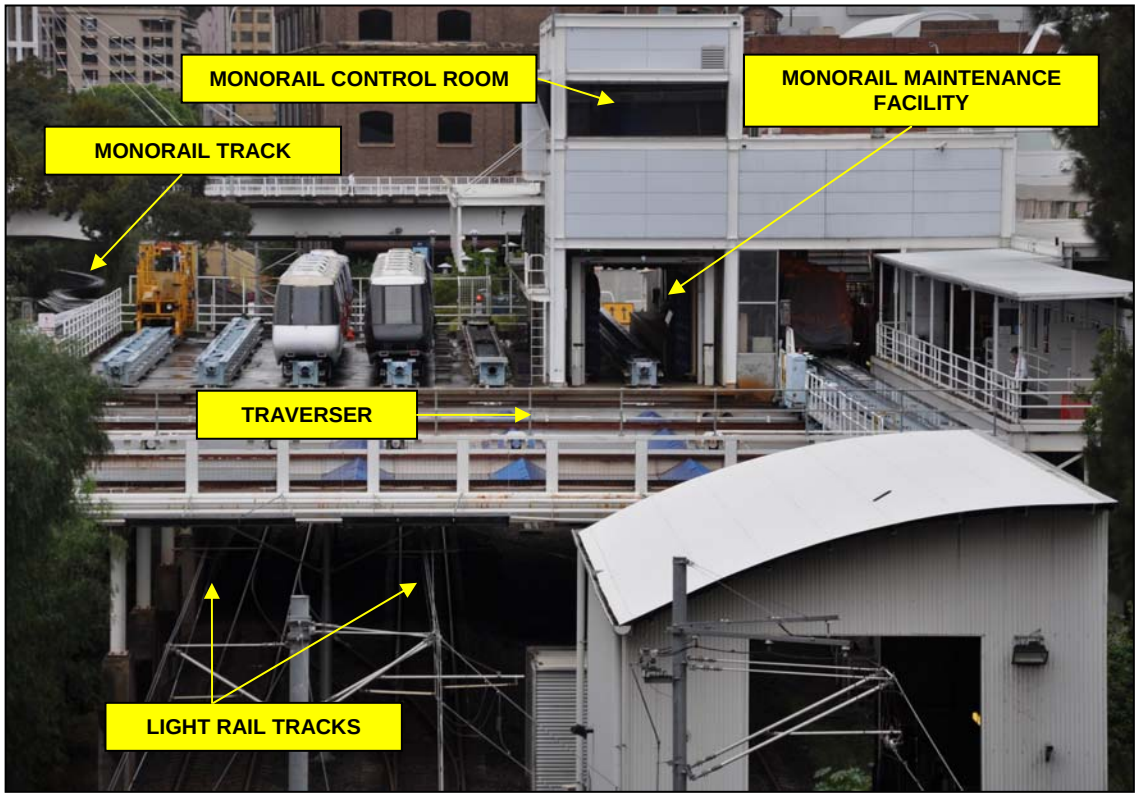

Photo 7: Monorail Maintenance and Control Facility

1.31 Each of the monorail stations is staffed by a station supervisor who supervises monorail movements at the platform and the operation of the ticketing system. Each station supervisor is qualified as a monorail driver. Communication between the control room and the station is via a landline phone or a two-way radio.

Employee Information

1.32 The Driver of Monorail 1 had seven years experience in driving monorails. He had started his shift on the day of the collision at 1:00pm when he signed on at Paddy's Market Station. He was scheduled to complete his shift at 9:00pm.

1.33 The Relief Driver had eighteen months experience in driving the monorail. He had commenced his shift at 3:45pm when he signed on at Galeries Victoria. He was working a relief shift which involves relieving other staff while they

take their scheduled breaks. He was scheduled to complete his shift at 9:15pm.

1.34 The Driver of Monorail 4 had about two months experience in driving the monorail and had started her shift at 11:00am. She had not taken any breaks during her shift which was scheduled to end at 4:00pm.

1.35 The Controller had five years experience in monorail operations including two years experience as a controller. He had commenced work at 2:30pm and was scheduled to complete his shift at 11:00pm.

Fatigue

1.36 The shift length and roster patterns for the three Drivers and the Controller were examined for the three weeks leading up to the collision. All three drivers had the preceding two days off and only worked part-time. They stated that this was their only job, although the Driver of Monorail 4 was also studying at university.

1.37 Rosters for the Driver of Monorail 1 indicated that he had only worked a total of 36 hours in the past fortnight; three hours of which were immediately prior to the collision. When asked at interview about his condition at the time of the incident, he stated:

> *"I'd had a good eight hours sleep. I exercised the day before. I ate well. I was fully awake and focussed … functioning at 100%*."

1.38 There was no evidence to suggest that fatigue contributed to this collision.

Environmental Conditions

1.39 The weather around the time of the collision was dry with clear skies. The temperature recorded at Observatory Hill, approximately one kilometre away, was 26.5°C at 3.00pm, with a 19km/h North-Easterly wind.

1.40 The presence of moisture or contaminants on the track can adversely affect braking performance of the monorail; however, there was no evidence of either being a factor in this incident.

1.41 At the time of the collision the sun's altitude was approximately 43°. Although the monorail was travelling West towards the sun's glare, it was deemed not to be a factor contributing to the collision.

1.42 The Driver of Monorail 1 stated that, while he was driving, he had the front windscreen raised to improve airflow. However, it was only raised to an angle of approximately 45° which meant that he would still need to look through the glass to check the track ahead. The front windows were clean and in good condition.

PART 2 FACTORS CONTRIBUTING TO THE COLLISION

Visibility

2.1 There are a number of locations where vegetation affects sighting distances for monorail drivers. In particular, a deciduous tree obscures the driver's view to the entrance of Darling Park Station for the majority of the way after departing City Centre Station (see *Photo 2*). This condition continues until approximately 40m from Darling Park Station where the view then becomes unobstructed. The station is also momentarily visible at a point approximately 220m away from the station, as the track crosses to the Southern side of Market Street. The Driver of Monorail 1 stated he did not see the stationary Monorail 4 until he had passed the tree.

2.2 The tree is growing on Market Street adjacent to the track (see Photo 8). The branches of the tree do not impinge on the track or the envelope of the monorail. Rather, it is the curvature of the track which causes the tree to block the view to the entrance of Darling Park Station. The issue of removal or lopping of the tree has been the subject of ongoing discussions between Veolia and the Sydney Harbour Foreshore Authority.

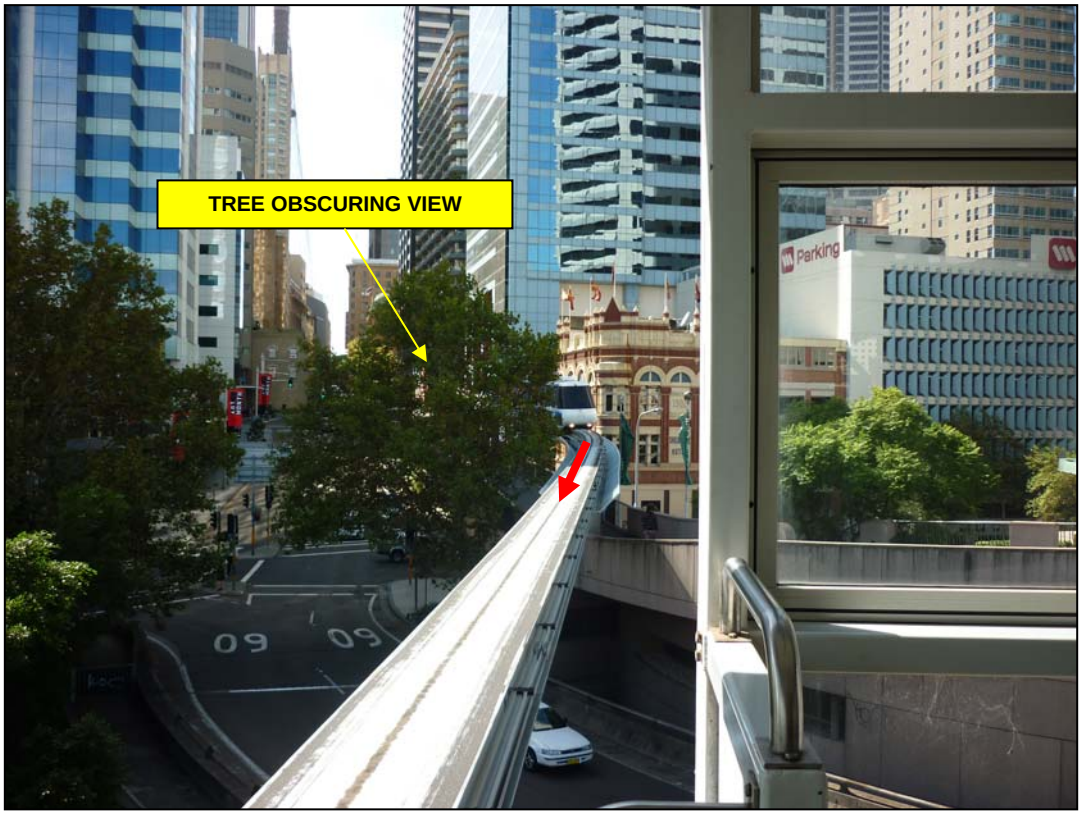

Photo 8: View from Darling Park Station towards City Centre

Driver Distraction and Reaction

2.3 Both the Driver and the Relief Driver stated that the Driver hit the emergency stop button only after the monorail passed the tree, 40m from the station, immediately after the first proximity alarm sounded. If this was the case, it would indicate there was a malfunction with the control system which caused it to activate 110m after it was intended to. The Driver stated that when he attempted to stop the monorail he did not feel any braking effect. The earlier automatic operation of the ACES system may explain the Driver's perception that there was a lack of mechanical and regenerative braking after he hit the emergency stop button. However, the testing which was conducted and the evidence which emerged during the course of the investigation supports the conclusion that there was no malfunction and that the ACES system activated as designed, some five to six seconds before the Driver reacted to the alarms.

2.4 **Alarm types.** It is a common feature of monorail operations for alarms to sound with some degree of frequency throughout the course of a day's service but these alarms typically do not indicate matters with major safety implications. A fault code will appear on the monorail dashboard and the information is sent automatically to the controller. Once an alarm is set off, the driver acknowledges the alarm and takes whatever action is necessary to respond to the circumstance indicated by the alarm.

2.5 **Noise distraction.** The noise from the ACES proximity alarm and the concurrent radio call may have affected how long it took the driver to react in this emergency situation. The first stage proximity alarm is a loud, beeping alarm that changes to a two tone alarm after the monorail travels a further 50m. In the front cab, these alarms are louder than the background noise caused by the electrical drives and general track noise. The alarm cannot be turned off once it sounds and will only stop sounding once the distance to the monorail ahead exceeds 150m.

2.6 When the Controller first radioed the monorail, the Relief Driver stated that:

> *"It appeared to me that (the Driver) did not fully understand what the Controller had said because he said "what was that" or some thing to that effect. I have also experienced trouble hearing base on the train comms due to background noises in the driver's cab*."

2.7 The Driver of Monorail 1 commented that the ACES proximity alarm *"… is very loud and very annoying".* The Controller stated that, when he spoke to the Driver of Monorail 1, he could hear the ACES proximity alarm sounding in the background. However, he *"… could not hear any responses from my calls".* The Driver's recorded response to the Controller's warning about a monorail being at Darling Park Station was to ask him to repeat the message, which he did.

2.8 According to research on auditory alarms:

> *"Designing collision avoidance warnings that are very urgent may reduce driver reaction time to warnings in a simulator setting, but the trade-off is that the resulting warning may annoy the driver and undermine system acceptance and eventually compromise driver response to the system in actual driving situations*."[3]

2.9 **Conversation Distraction.** At the time the cab alarms sounded, the Driver was seated at the controls with the Relief Driver standing behind. Both stated that they were conversing when the alarms activated. When interviewed about this conversation the Driver stated that:

> *"Driving in manual I have to face the front and watch where I'm going and I've got to judge the speed and where I'm going to slow down and everything so all I hear is a voice in my head in the back*."

Conversation within the cab can have a detrimental effect and be distracting for the driver operating the controls. According to the National Highway Traffic Safety Administration (NHTSA), driver distraction was most likely to be the cause of rear-end collisions in which the lead vehicle was stopped.[4] Other research has found that passenger conversation interferes with appropriate hazard detection and response.[5]

2.10 **Radio Call Distraction.** After the first alarm, the Driver was contacted by the Controller who warned of the stationary monorail ahead. Such radio conversations have been likened to mobile phone conversations which research suggests can cause inattention and increase the time it takes to

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3 EE Wiese & JD Lee, 'Auditory alerts for in-vehicle information systems', *Ergonomics*, vol. 47, no. 9, 2004, pp. 965-986.

4 TA Ranney, E Mazzee, R Garrott, and M Goodman, '*NHTSA Driver Distraction Research: Past Present and Future*', published 5 July 2000, accessed on NHTSA website http://www.nhtsa.gov/

5 CB White & JK Caird, 'The blind date: The effects of change blindness, passenger conversation and gender on looked-but-failed-to-see (LBFTS) errors', *Accident Analysis and Prevention,* vol. 42, 2010, pp.1822-1830.

react to hazards. According to the Monash University Accident Research Centre:

> *"Both the physical and cognitive distraction caused by using mobile phones while driving can significantly impair a driver's visual search patterns, reaction times, decision-making processes and their ability to maintain speed, throttle control and lateral position on the road."* [6]

2.11 The radio call from the Controller to the Driver came at a critical time. From the time the first alarm sounded, 150m from the monorail ahead, the Driver had 50m in which to take braking action before the 100m mark where any action to slow the monorail would be taken automatically by the ACES system. Travelling at the speed profile of 8.5m/s, or the estimated speed of 9.5m/s, the system provides for approximately five seconds to react (see *Figure 2)*. Despite the distractions, the Driver had adequate time to react to the alarm and apply the brakes.

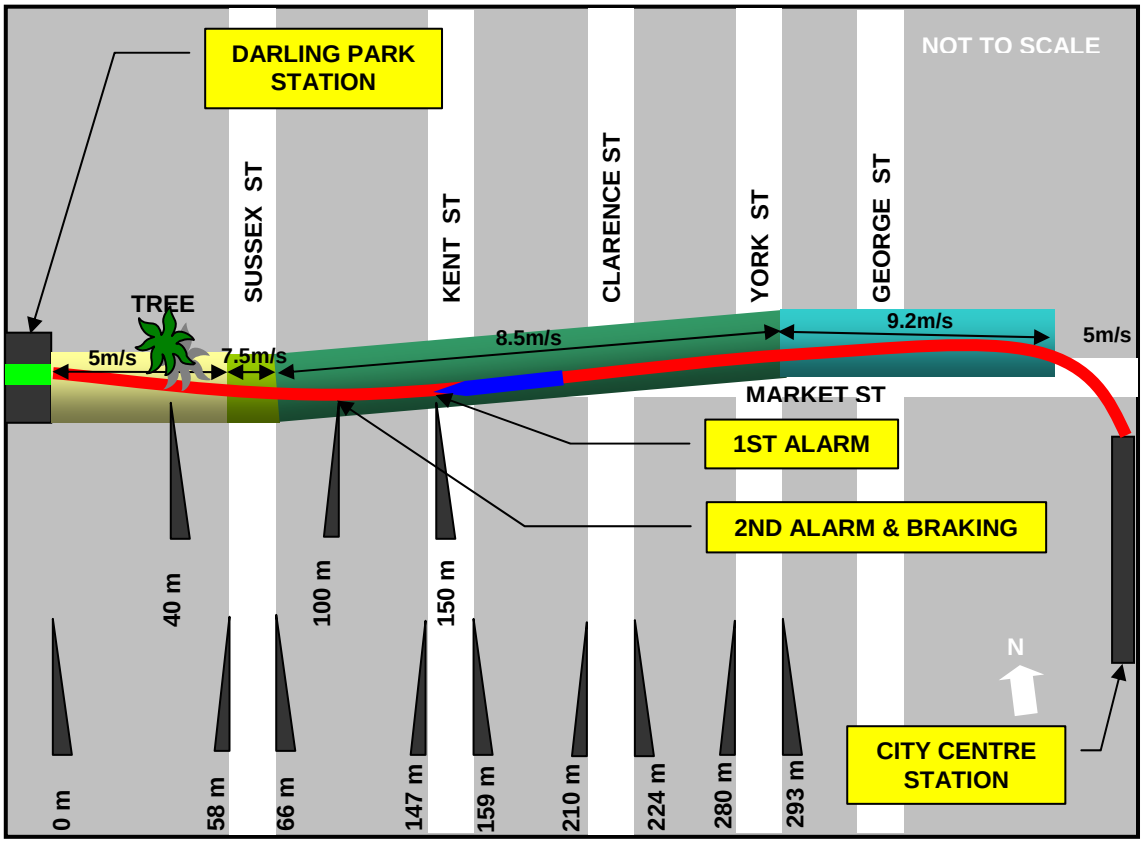

Figure 2: Speed profiles and distances to Darling Park Station entrance

[6] K Young, M Regan & M Hamer, '*Driver Distraction: A Review of the Literature*', Monash University Accident Research Centre Report No. 206, published November 2003, accessed on Monash website http://www.monash.edu.au/muarc/reports/muarc206.html

Control System Functionality

2.12 At the time of the collision, each monorail was fitted with a microprocessor-based control system known as the Autopilot.[7] Designed and built in 1988, the system had reached the end of its 20 year service life and Veolia was in the process of upgrading the control system which had already started with Monorail 2 in 2009. The anti-collision measurement and detection circuitry is contained within the Autopilot module. If activated these circuits cause the main PLC to sound alarms in manual mode. The Autopilot was located in the front carriage of each monorail and was interchangeable between monorails.

2.13 Originally the system was intended to be able to operate in three different control modes: automatic, semi-automatic and manual, with automatic the preferred mode of operation. The selection of manual mode was designed to be done when the monorail was stationary and only on authority of the controller. A dashboard key-operated switch controls the modes (see *Photo 9*).

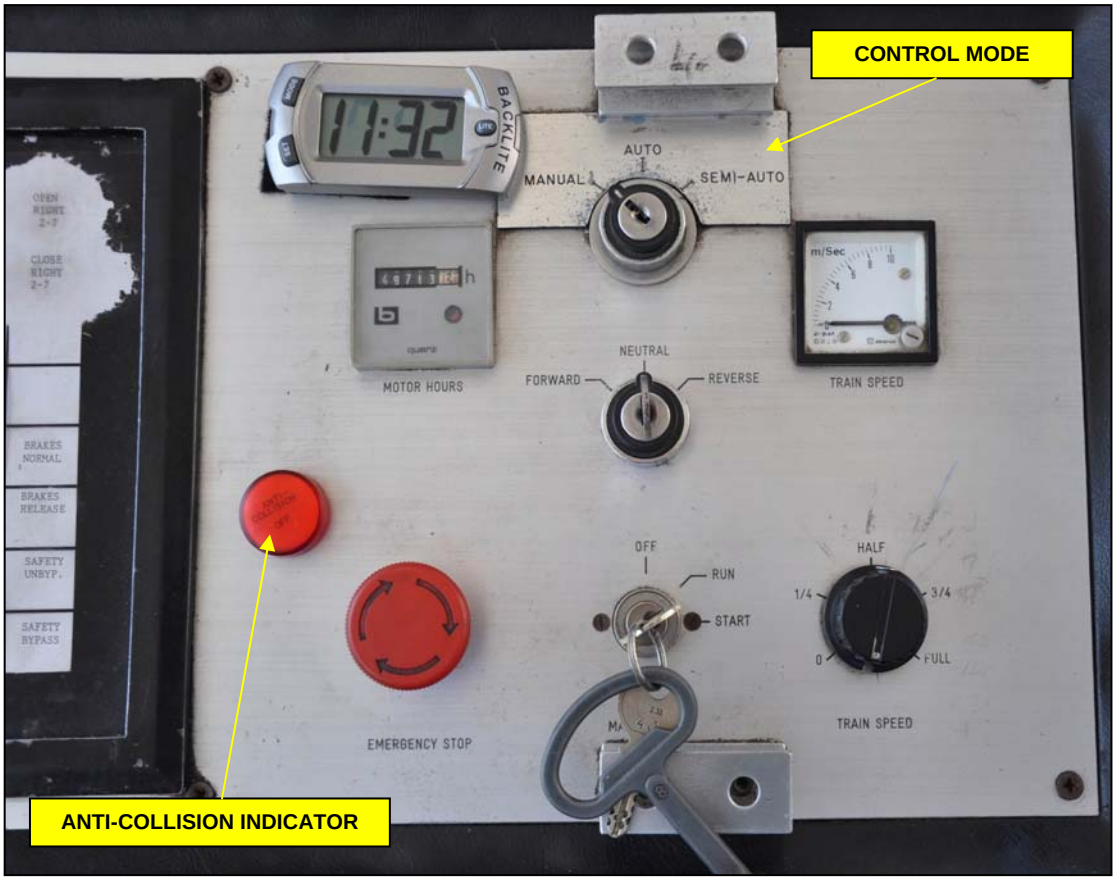

Photo 9: Monorail dashboard (right side)

[7] Since the collision all monorails have been fitted with a new control system.

2.14 At the commencement of daily operations, all monorails are operated initially in manual mode to ensure that monorail drivers remain skilled in this mode of operation and that the monorail is operating normally. Should a reliability problem be detected during this commencement period, the driver is instructed to stay in manual mode while maintenance staff attend to the problem. If the problem cannot be rectified immediately but the monorail is still safely operable, the driver then continues in manual mode for the duration of the shift where he maintains lookout and separation on advice from the controller. The controller's role is to ensure that monorails are maintaining safe headway.

2.15 In manual mode, drivers are required to manually control the speed. Typically there is little separation between monorails and a number of areas have restricted visibility of the track ahead. Driving around the 3.6km loop track is repetitive, with frequent braking and control tasks to complete at each station. If a manual system is operating, a reliable automatic anti-collision system is essential as a safety defence.

2.16 After the initial period of about 60 to 90 minutes of driving in manual mode and the reliability of the system has been established, drivers are then instructed by the controller to switch to semi-automatic mode.

2.17 Semi-automatic mode allows the driver some control functions, such as station dwell time and door closing functions. In this mode, the Autopilot detects the position of the monorail and, on arrival at a station, opens the doors on the platform side of the monorail.

2.18 Importantly, in semi-automatic mode the control system also assists in maintaining a safe separation distance. It automatically adjusts the monorail's speed and stops it when the distance to the monorail ahead reduces below the pre-determined limit of 100m. Operating the monorail using the semi-automatic control system removes a number of risks associated with driver error.

2.19 In automatic mode the monorail is able to function driverless. All operations are performed automatically, including door opening and closing, speed control and braking. This mode was intended to be the default mode but has never been utilised. Concerns about the reliability of automatic operation and the desire to keep some driver control resulted in the other modes being

preferred. Further concerns were also raised about the driverless system failing to detect persons caught in doors or walking on the track.

2.20 **ACES System.** After a similar collision in 2006 an additional control circuit, the ACES system, was added to the Autopilot control system. The ACES device is an additional piece of equipment interfaced to the main PLC that intervenes and takes action to override the driver if the driver takes no notice of the alarms and does not take action to slow down sufficiently. The commissioning of the ACES system began on 26 July 2007 and it became operational in September 2007. The ACES system is only active when operating in manual mode. This is due to the Autopilot already controlling the anti-collision function in semi-automatic mode. Veolia's information states:

> "*When the monorail is in manual mode and the distance between the two monorails is less than 150m, the first audible alarm sounds. The monorail can still be operated. When the distance between monorails reduces to less than 120m*[8]*, the second audible alarm sounds and the ACES system activates and initiates an emergency stop function and the monorail comes to a halt at the specified emergency braking rate (note this may vary depending on the gradient of the beam).*"[9]

2.21 In this incident, the ACES system did not stop the monorail in time to prevent the collision. One explanation suggested by Veolia was that the anti-collision system was bypassed by the Driver after the alarm sounded since the switch to this can be accessed by the driver. It is located on a maintenance panel on the driver's dashboard under a secured lid (see *Photo 10)*. The drivers have the key and are instructed to access the switch at the direction of the controller in the event of a system failure or if a monorail-to-monorail tow is required.

2.22 When the anti-collision bypass switch is turned off, an in-cab audible alarm sounds and is the same frequency and pitch as the proximity alarm. Importantly, an alarm log is sent to the controller and a light is illuminated on the dashboard. However, in this case, there was no event log record to indicate that the anti-collision bypass switch was turned off at any time.

8 At the time of the collision the second alarm and emergency brake application were set to 100m.

9 Veolia Memo, '*Manual Anti-Collision Emergency Stop (ACES)*', issued 13/09/2007.

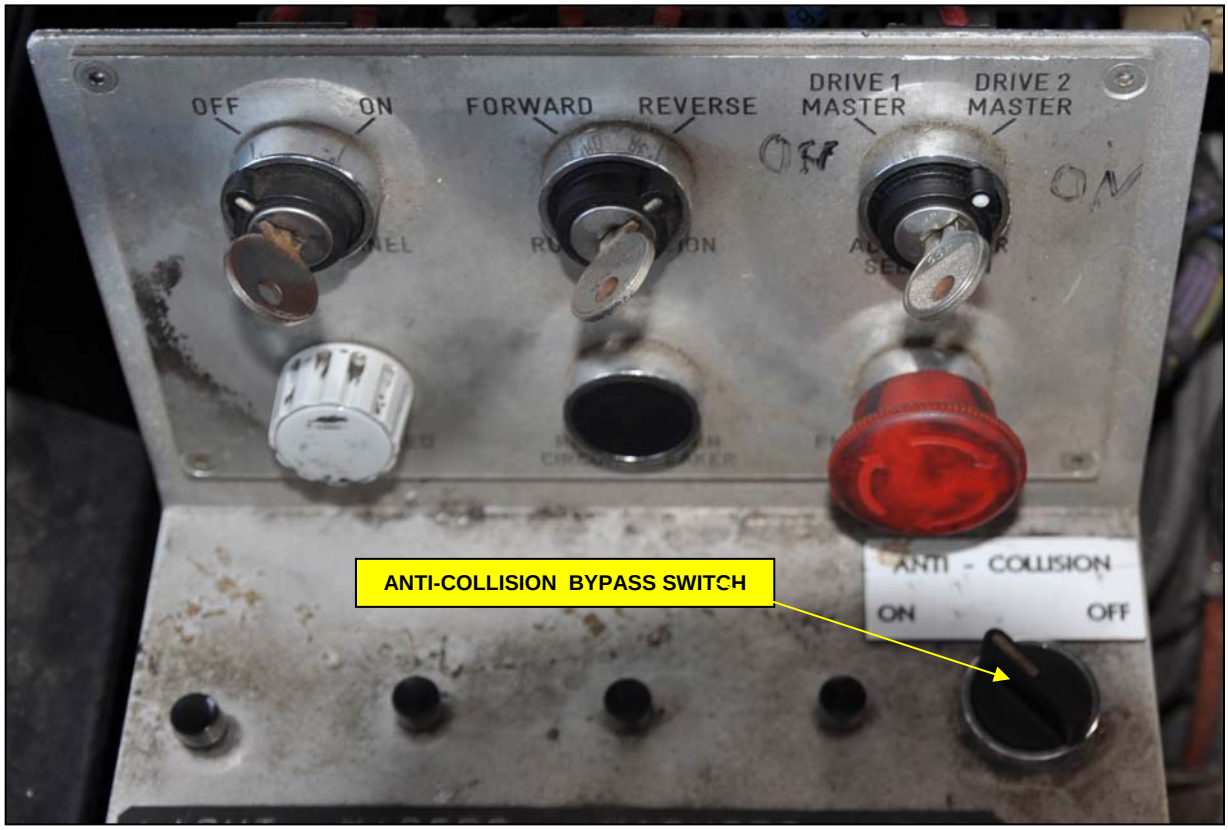

Photo 10: Monorail Maintenance Control Panel

2.23 There is no evidence, therefore, to support the contention that the anti-collision system was bypassed. It is unfortunate that the data from the control room was not recorded as it would have shown whether or not the switch was changed in the minutes leading up to the collision. Both the Driver and the Relief Driver in Monorail 1 denied that the anti-collision bypass switch was turned off prior to the collision. It would be an unusual action to be performed with the anti-collision alarm sounding and limited visibility of the station ahead.

2.24 **Autopilot.** At the time of the collision there were six functioning Autopilot units available for utilisation across the monorail fleet. The contract to repair these Autopilots was with the company that had designed them, Trantek Pty Ltd, but the maintenance contract ended in December 2009 and, from then on, all maintenance was undertaken internally. One maintenance technician said of the Autopilot units:

> *"I treat them like hens teeth, they are very delicate*."

It should be noted that Veolia was in the process of replacing the Autopilot at the time of the incident with a new Anti-Collision Control system as part of the upgrade project.

2.25 Autopilot 4 (AP4) was fitted to Monorail 1 at the time of the collision and an out-of-service tag (096-476) was attached to it (see *Photo 11)*. According to the attached tag, dated 10 February 2010, AP4 was "*getting lost around the system*". It should be noted that no subsequent fault was found with the AutoPilot and it is believed not to be a contributing factor to the collision. However, the job sheet relating to this tag was lost so any repairs conducted during the intervening time could not be determined. Maintenance records indicated that the Autopilot was reinstalled in Monorail 1 on 24 February 2010 stating that Monorail 1 "*Needs track testing*". A Pre-service Inspection dated 25 February 2010 stated: "*AutoPilot Faulty, to be left in manual*". The maintenance technician who reinstalled AP4 into Monorail 1 said:

> *"I was concerned with the operation of AP4 due to it being on the bench and its previous problems*."

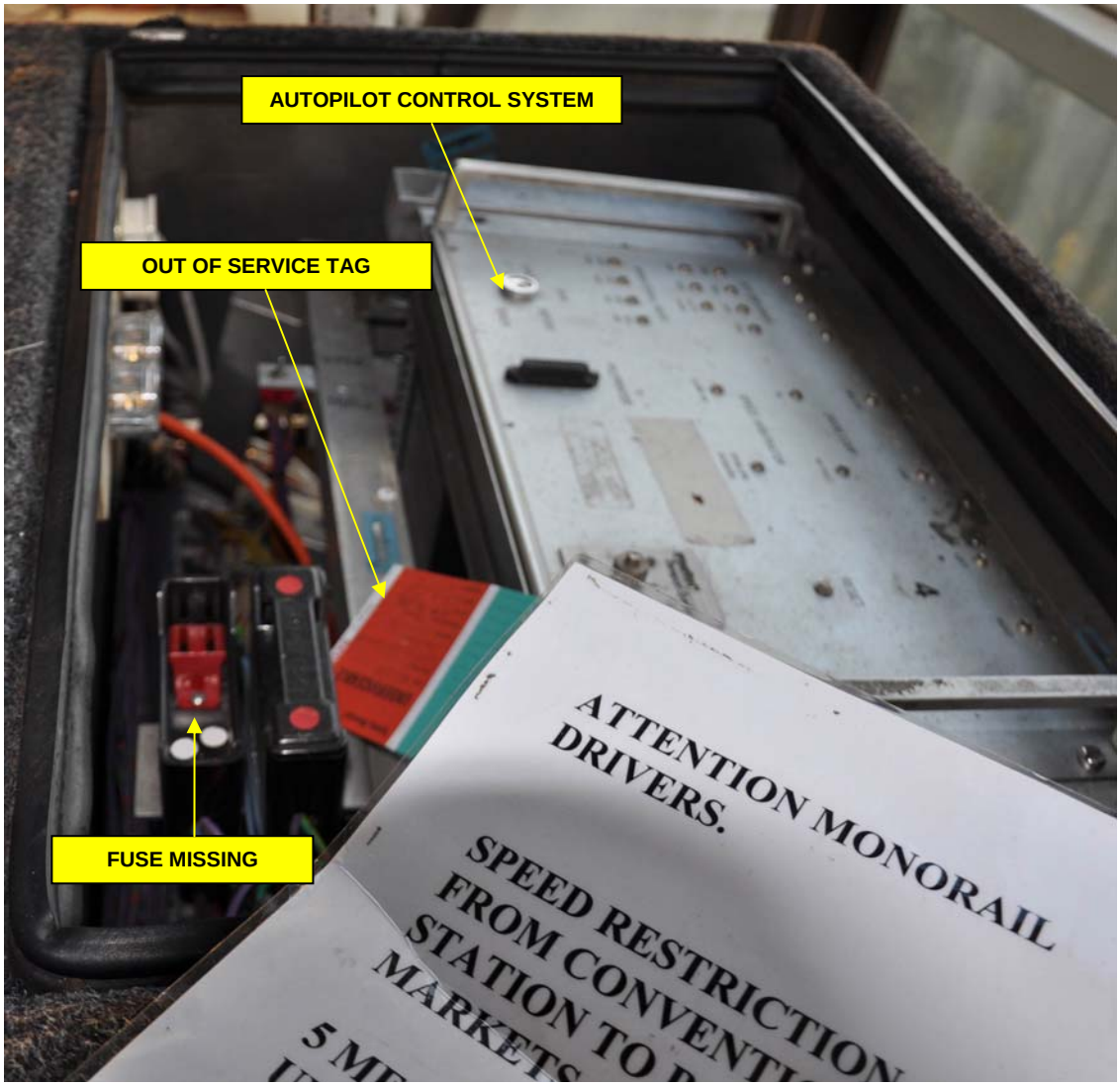

Photo 11: Autopilot Control System after collision

2.26 According to the maintenance records, Monorail 1 did not undergo any track testing before being put into service on the day of the collision. When it entered service at 6:42am it did so in manual mode. It was taken out of service at 9:34am due to drive problems but was returned to service at 11:10am.

2.27 Some onboard data recording concerning the diode loop is stored in the Autopilot, however, no data was recoverable from the Autopilot following the collision. The information stored is in the form of volatile memory and, when software was reinstalled, any data present was erased. Veolia stated that when the software was reloaded the Autopilot appeared to run normally. The Autopilot was then placed in Monorail 6 and three test runs were undertaken by Veolia staff. No faults were found during these trials. It is unfortunate however, that the integrity of evidence was not preserved until an independent evaluation of the Autopilot had been undertaken.

2.28 **Distance and brake settings.** The track between City Centre and Darling Park is the steepest downhill gradient on the monorail loop. Trials verified that the emergency brake application settings were incorrect if the monorail was being driven at 9.5m/s in that the distance from the station was insufficient. It is unknown what tests were carried out to determine the appropriate distance settings when the ACES system was introduced in 2007. This latent problem was only discovered as a result of this collision and as a result of numerous trials to determine why the ACES system did not stop the monorail in time.

2.29 The ACES system has now been replaced with the Anti-Collision Control (ACC) system. The ACC system activates and restricts the speed to 5m/s in the first instance at 400m, to 2.5m/s at 250m, to 1m/s at 200m and finally applies the emergency brakes at 140m from another monorail. Once the monorail in front is within 170m the anti-collision audible alarm sounds and will only stop sounding once the monorail in front is back again beyond 170m. This appears to be an improved braking profile.

2.30 **Fuse missing.** When originally inspected, one of two fuses in the power supply to the AutoPilot on Monorail 1 was found to be missing from its socket (see *Photo 11*). This was originally thought to be a contributory factor to the collision. However, a maintenance technician reported that it was found in the

cab of the monorail a few days later by another maintenance staff member. Tests demonstrated that the fuse clipped into the bracket vertically and the force necessary to remove the fuse made it unlikely that it became dislodged by the collision. Without the fuse, the monorail would have stopped or had its speed restricted to 2m/s. As such, it is believed not to be a contributory factor and was most likely removed by an unknown person immediately following the collision.

PART 3 RELATED ISSUES

Communication Systems

3.1 Communication between drivers and the controller is made by two-way radio which was functioning at the time of the collision. However, analysis of the voice communications made around the time of the collision was difficult due to the poor audio quality.

3.2 The AutoPilot is connected to the main PLC which automatically transmits the position of each monorail on the system, changes to any monorail settings by the driver and all alarms or faults to the control room by radio. However, Monorail 1 was in a data communications black spot at the time of the collision due to an intermittent but known problem with radio frequency transmission in the section between City Centre and Darling Park Station. This black spot problem is a long-standing one and is known by all drivers, controllers and management. One of Veolia's managers stated:

> *"Communication had been lost, which we know that that particular section of track is prone to being a black spot. Not all the time, but it's a black spot."*

Veolia's report into the 2006 collision also recommended that:

> *"All monorail controllers should be made aware of the importance of monitoring the headways of monorail vehicles …"*

3.3 With the monorail's position being lost on the SCADA system, the ability of the controller to have full visibility of the positions of all the monorails on the loop is seriously compromised. In this case, the Controller did not know the exact position of Monorail 1. However, when he became aware of the delayed Monorail 4, his communication to all parties was prompt.

3.4 **CCTV on platforms.** At two stations, Harbourside and City Centre, there is a CCTV screen in position at the end of the platform to assist the drivers in seeing if there is a monorail at the station ahead. While helpful, its use is limited as it does not show any monorails on the track between stations and, as such, has the potential to give drivers a false impression of what is ahead.

3.5 **Signalling system.** Unlike those used in conventional railway networks, there is no signalling system in place on the monorail loop. However, at some stations, there is a timer signal which can be altered depending on the number of monorails operating on the loop (see *Photo 12*). The signal indicates to a driver that the monorail ahead of it has departed more than two minutes before the monorail at the timer signal. This system relies on each driver remembering to press the timer button on departure from the station. Like the CCTV system, it cannot give any indication of a stationary monorail in the section ahead. Prior to the installation of the timer signal system, a different signalling system had been trialled at Paddy's Market Station using sensors to relay information to a signal to indicate if the section ahead was occupied, but the trial found the system to be ineffective.

Photo 12: Signal for drivers to proceed

3.6 Veolia's report into the 2006 collision recommended that:

> "*The remainder of the monorail system is checked for locations where interlocked signals may assist in reducing the risk further*".

However, Veolia has advised that its upgrades to the Monorail's onboard information system will give the driver a reliable picture of the location of other monorails on the system.

Maintenance

3.7 The maintenance of the monorail and track is conducted in-house. There is a dedicated service area for one monorail and space to store five monorails outside the maintenance facility (see *Photo 7*). At the maintenance facility, all detected faults, repairs and maintenance tasks are entered into both a written log book and a computerised maintenance history. Veolia could not supply all of the relevant records when requested as some entries had been inadvertently disposed of during a recent upgrade of the computer system. In particular, the signed job sheet that was associated with the out-of-service tag found on the Autopilot in Monorail 1 after the collision could not be provided.

3.8 **Track Tape.** The track tape provides increased traction and adhesion between the wheels and the track. The condition of the tape on the approach to Darling Park Station appeared to be serviceable with approximately 80% track coverage. Maintenance records indicated that a significant amount of new track tape had been laid at various locations on 19 January 2010. However, an inspection of the track immediately following the collision showed that the tape was in a worn condition at many locations (see *Photo 13*).

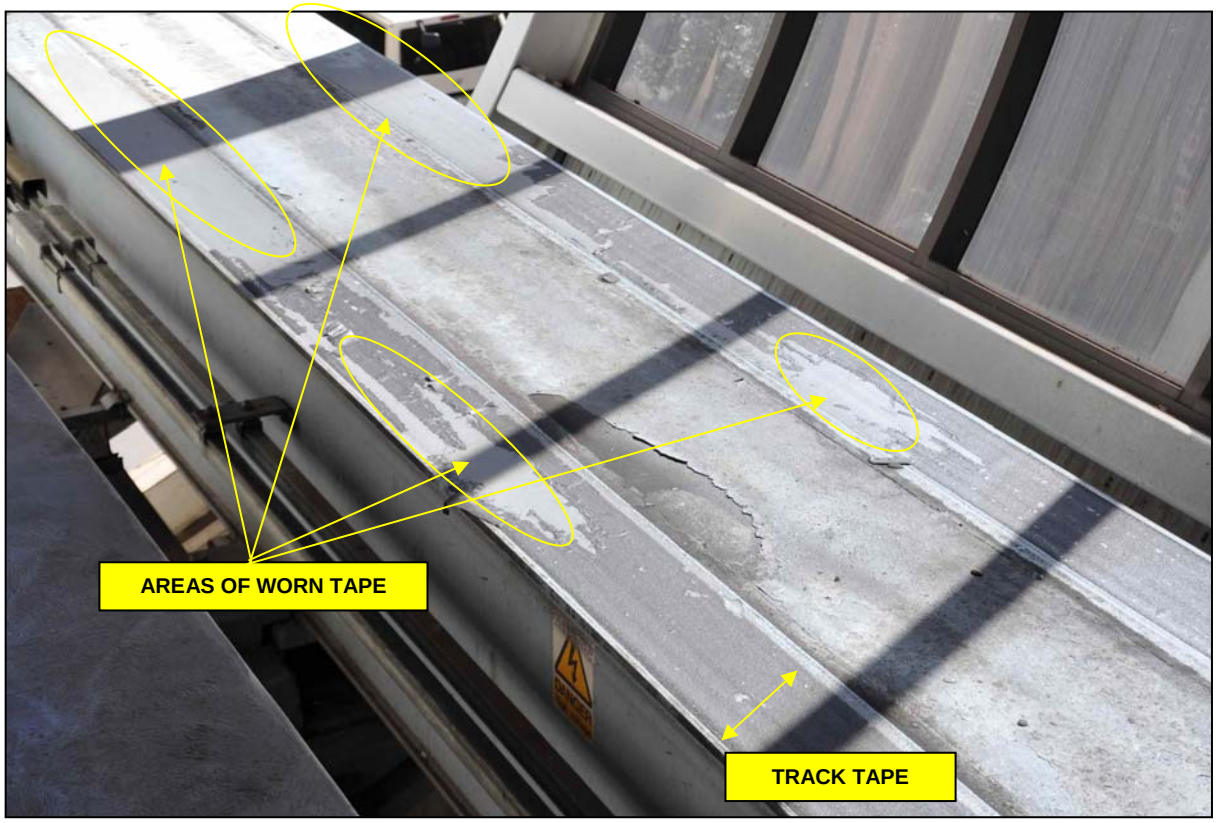

Photo 13: Track tape at Galeries Victoria Station

3.9 Veolia's Report[10] into the 2006 collision identified that a lack of track tape may have been a contributory factor to that collision and the recommendation that the tape be inspected and replaced where necessary was acted upon.

3.10 **Signage.** While inspecting the condition of the track tape, faded warning signage relating to "Authorised Personnel Only" was observed on the track near the point of the collision (see *Photo 14*). Although not a contributory factor in this collision, warning signage, where fitted, must be maintained in a legible condition.

Photo 14: Safety sign and track tape at Darling Park Station

3.11 **Door Closing Problems on Monorail 4.** Monorail 4 was experiencing door problems throughout the day. The previous Driver of Monorail 1 had changed from Monorail 4 at Paddy's Market Station only four stations before the collision. The decision to switch drivers was made by the Controller on the basis that the Driver on Monorail 1 was about to finish her shift and Monorail 4 was suffering continual door problems. Monorail 4's maintenance history recorded 33 door faults in the previous 12 months. Yet, in contrast, Monorail 1 had eight door faults recorded for the same period. An ITSR report[11] written

[10] Veolia Investigation Report, '*Monorail Vehicle Collision 4 September 2006*', p.25. Unpublished internal report.

[11] ITSR Field Report from inspection carried out on 20 October 2006. Unpublished internal report.

after a compliance inspection as a result of the 2006 monorail collision identified that there were also door closing problems on one of the vehicles involved in that incident

Testing and Trials

3.12 **Testing of electrical, braking and control systems.** Following the collision, various tests were undertaken on the electrical, braking and control systems on Monorail 1 by Veolia and witnessed by OTSI and ITSR investigators. Although Monorail 1 was damaged and unable to be driven around the track, it was still possible to conduct functionality tests on the individual components and systems. This testing demonstrated that there was no failure of the braking system and that the mechanical brakes were functioning properly before the collision and provided sufficient stopping capability. Further, as the mechanical brakes operate on a 'failsafe system', any loss of power would have resulted in the brakes being applied automatically. The electrical circuitry into the emergency stop button was also tested and found to be fully functional.

3.13 During playback of the audio recordings associated with the incident, a proximity alarm could be heard in the background during the conversation between the Driver and the Controller. The single tone alarm can initially be heard before it then changes to a two-tone alarm. The fact that these alarms can be heard indicates that both the Programmable Logic Controller (PLC) and AutoPilot were functioning correctly in relation to the ACES system. The hardware associated with the ACES system also functioned correctly during post-collision testing.

3.14 As a result of all the tests, it can be concluded that all electrical, braking and control systems on Monorail 1 were operating as designed at the time of the collision. Evidence from the audio recordings corroborates this finding.

3.15 **Track Trials.** Trials were also conducted with other functioning monorails to check their performance at varying speeds and under a variety of settings and loads, in particular on the section of track approaching Darling Park Station. OTSI and ITSR investigators were present to witness the performance of these monorails under different operating conditions. Veolia also conducted another set of trials and the results of these trials were provided in a detailed

technical report. The results of these Veolia trials were consistent with what was demonstrated in the witnessed trials.

3.16 However, there was one feature of differentiation during all the trials in that there were at most only seven persons on board, where there were 17 persons on Monorail 1 at the time of the collision. In some Veolia trials, approximately 1,000kg of water was placed on board to replicate the loading at the time of the collision. It was found that with an increased load the stopping distance of the monorail was marginally increased.

3.17 Although Monorail 1 had only four of the six drive units operating on the day of the collision, trials demonstrated that the difference in the number of drives did not adversely affect the stopping distance when the ACES system activates. Indeed, the trials established that the monorail relied mostly on mechanical braking to stop because the operation of the Emergency Stop Timer is supposed to disengage the regenerative braking approximately 0.5 seconds after the emergency stop button is activated.

3.18 **Track Trials Results.** Trials were conducted on 28 February 2010, 16 March 2010, and 23 April 2010 and again on 1, 4 and 10 February 2011. The most significant trials are described below.

3.19 On 16 March 2010 the monorail was driven at 6m/s in manual mode towards Darling Park Station with seven persons on board. As there was no other monorail at Darling Park Station the ACES system was inactive and the trial only tested braking performance by driver activation. The driver was instructed to press the emergency stop button at the tree, when he had full visibility of the station, about 40m from the station. As a result, the monorail stopped approximately 20m before the entrance to Darling Park Station. This demonstrated that a monorail driven under control of the driver, who activates the emergency brakes at full sighting of the station, will stop before the station. It should be noted that the Emergency Stop Timer activated the regenerative brakes on one motor for five seconds rather than the scheduled 0.5 seconds, meaning an increase in braking effectiveness from what occurred on the day of the collision.

3.20 On 23 April 2010 a monorail was driven at 6m/s on the approach to Darling Park Station with seven persons on board. On this occasion, the electrical circuits at the entrance to Darling Park Station were bridged to simulate a

monorail standing at the station. This trial was to ensure that the ACES system would activate automatically without any driver intervention. The first level alarm sounded at 150m from Darling Park Station, as designed, before the second level alarm and brakes engaged at 100m. The monorail stopped approximately 80m from the station. Again the regenerative braking had remained active for five seconds instead of the specified 0.5 seconds. This showed that the monorail driven slower than the speed profile, with the regenerative braking activated for a longer period should stop well before the station.

3.21 On 1 February 2011, the monorail was tested at 9.5m/s with three persons on board, again with the electrical circuits bridged at the entrance to Darling Park Station. Four drives were operating on the monorail and also the Emergency Stop Timer setting was 0.5 seconds. This test was the closest simulation to the Monorail 1's settings on day of the collision. The first level alarm sounded at 150m from Darling Park Station, as designed, before the second level alarm and brakes engaged at 100m. The monorail entered the station at a speed of approximately 6m/s and stopped 16m inside the station, thereby establishing that the settings had been incorrectly calculated in the first instance.

Previous Incidents

3.22 There have been few reported major incidents on the Monorail system since it started operation in 1988. The most significant occurred in September 2006 when Monorail 4 collided with the rear of Monorail 6, again at Darling Park Station. The Driver of Monorail 4 said that he had reduced speed by switching the speed to neutral as he approached York Street and then activated the emergency stop button at Kent Street at the same time the anti-collision alarm commenced an audible alarm. The monorail did not stop in time and collided at low speed with the rear of the stationary Monorail 6. Veolia's investigation report[12] concluded that:

> *"On the balance of probabilities Veolia Transport Sydney (VTS) is left with drawing either one of two conclusions; something unknown or not considered by VTS has played a significant role in the incident; or the*

[12] Veolia Investigation Report, op.cit., p. 25.

> *driver did not activate the emergency stop button until after the second of the two-tone anti-collision alarms. What is clear however is that the following factors may have contributed to the incident; the lack of track tape on the monorail beam; and the lack of headway management by the controller … the incident highlights the potential factors which may also increase the likelihood of a collision between two monorail vehicles – particularly in manual."*

The report also found that Monorail 4 was put into service despite having earlier problems with the drive in car 1. A maintenance technician stated that:

> *"Whilst removing Monorail 4 from system it was noticed that Monorail 4 on Drive initialization became erratic in operation."*

No major faults were found with Monorail 4 during the subsequent investigation.

3.23 The same tree that obscured the view of the entrance to Darling Park Station in the 2010 collision was also identified as a contributing factor in the 2006 monorail collision. The Veolia investigation report[13] stated:

> *"The view from car 1 of a monorail vehicle approaching Darling Park Station was obscured by a tree located on the western side of Sussex St."*

However, no recommendation was made in relation to the tree. Since then Veolia has made a number of unsuccessful approaches to the Sydney Harbour Foreshore Authority to have the tree pruned or removed.

3.24 Veolia's report also recommended that an interlocked signal system be installed at City Centre Station to provide drivers with information about other monorails occupying the section to Darling Park Station. This recommendation was not acted on.

3.25 One recommendation acted on was the addition of the ACES system when the monorail is being driven in manual mode.

Incident Response

3.26 Procedures for monorail evacuation when monorails are between stations are documented in Veolia's Emergency Procedures Manual. The Manual recommends that a monorail or maintenance vehicle be used to push the

[13] Ibid. p. 18.

disabled monorail into the next station to enable the evacuation of passengers through the doors and onto the platform. This avoids the more difficult evacuation through the restricted emergency access windows. In this case the procedure was not implemented as the front of Monorail 1 was inside the station entrance and any push may have increased the risk of debris falling onto the road below, and may also have created further damage to the monorail's structure and integrity.

3.27 Other railway organisations with restricted access environments, such as the Perisher Skitube Alpine Railway, conduct regular training exercises in conjunction with emergency services who comment on the success or otherwise of the exercise. Along with Veolia's regular internal drills, a training exercise involving external parties may be a beneficial way to ensure that emergency services, along with Veolia employees, thoroughly understand emergency access and evacuation procedures.

3.28 Despite the incident being classified as a Category A notifiable incident[14], there was a two hour delay in notifying ITSR and OTSI of the incident. By the time the OTSI investigator arrived at the site Veolia staff had commenced clearing debris and moving damaged panels.

Other Safety Matters

3.29 **ITSR Audits.** Since December 2004, ITSR has completed seven audit and inspection activities on the Sydney Metro Monorail system. Six audits have been conducted since Veolia commenced management of Monorail operations.

3.30 In its November 2008 report, ITSR stated:

> *"There are obvious signs that the monorail system (track and rollingstock) is becoming antiquated, this presents quite a significant range of risk factors for the operator."*

In an August 2009 audit report, ITSR commented that:

> *"Veolia must focus on further developing a comprehensive Safety Action Plan to ensure corrective actions are created and implemented."*

14 *Rail Safety (General) Regulation 2008*, Clause 27.

At the time of the collision there were no outstanding findings relating to ITSR audits.

3.31 **Electronic Data Recording.** A number of problems with the recovery of electronic data were encountered after the incident. These included:

- no Control Room event log recordings between City Centre and Darling Park Stations existed due to transmission inconsistencies, a problem known to Veolia and not confined to just one location;
- time stamp discrepancies between voice and CCTV recordings; and
- poor audio recordings which made it difficult to understand the conversations between the Controller and the Driver.

However, they were not contributing factors in the collision.

Remedial Actions

3.32 Since the collision, Veolia has instituted a number of changes which are described below.

3.33 **Control System Replacement.** The Autopilot and ACES components have been replaced with an improved Anti-Collision Control system.

3.34 **Revised Work Instructions.** All drivers are now required to contact the control room once they have arrived at Galeries Victoria Station and obtain permission from the controller before proceeding to the next station, City Centre. The controller then authorises the monorail to proceed from Galeries Victoria once the monorail ahead has departed Darling Park Station.

3.35 **CCTV Monitoring.** A CCTV monitor has been installed on the platform of City Centre Station adjacent to the driver's cab stopping location. This monitor gives vision of the platform at Darling Park. Included on the monitor is a time and date stamp to verify that the feed is live and not frozen.

3.36 **Event Recording.** There was a problem with the capture of event data from the monorail at the time of the collision. Veolia had commenced upgrading this system prior to the collision. A CCTV camera has also been installed in the control room to capture the actions of the controller, and drivers' cabs have now been fitted with CCTV cameras that capture footage of the driver, control panel and the beam in front.

3.37 **Projects currently underway.** Veolia has reported that it has also initiated the following improvements, a number which were commenced prior to the collision. These improvements include:

- the installation of an Ethernet system to all Monorail vehicles to eliminate the radio frequency black spots and ensure vehicles remain in-scan at all times;
- the installation of a mimic SCADA system in the driver's cab to provide visibility to drivers of other monorails on the system; and
- the installation of new traction and control systems.

PART 4 FINDINGS

Causation

4.1 The investigation established that Monorail 1 was travelling above the speed profile at the time of the collision and that the Driver did not react quickly enough to brake the monorail when the first of two alarms sounded, warning him of the presence of another monorail 150m ahead.

4.2 The Anti-Collision Emergency Stop (ACES) system on Monorail 1 should have prevented the collision but it did not do so. While the ACES system activated the emergency brakes, they did not stop the monorail before it entered Darling Park Station because the design of the braking system and the ACES distance settings made no allowance for monorails being driven above the speed profile of 8.5m/s.

Contributing Factors

4.3 The Driver of Monorail 1 was likely to have been distracted at a critical time on approach to Darling Park Station by one or more events, including a conversation with the Relief Driver at the time the first proximity alarm activated, and by a radio call from the Controller before the second proximity alarm.

4.4 The view to Darling Park Station was obscured by tree foliage which prevented the driver from having a clear view to the station entrance, and the stationary Monorail 4 therein, until he was 40m from it.

Other Safety Issues

4.5 Although in a satisfactory condition on the approach to Darling Park Station, track tape that provides increased adhesion for traction and braking was worn on many other parts of the track. The documentation for track tape inspections and maintenance was incomplete.

4.6 Maintenance history documentation, in particular Job Sheet 096-476, for the Autopilot in Monorail 1 at the time of the collision could not be located or provided.

4.7 Two sets of doors on Monorail 4 did not open electronically following the collision and required the station supervisor to open the doors manually to evacuate passengers.

4.8 The poor quality of recordings of audio conversations between the driver and train controller made it difficult to decipher the detail of the conversations when played back.

4.9 The AutoPilot event recorder in Monorail 1 at the time of the incident did not record any data in the lead-up to the collision.

4.10 The loss of radio data communication meant a loss of event data from the monorail making it more difficult to determine the events preceding the collision.

4.11 The loss of radio data communication caused the Controller to lose awareness of the exact location of the monorail between City Centre and Darling Park Stations.

4.12 There were significant time discrepancies between Veolia's visual, audio and data recording devices.

4.13 The possibility exists for monorail drivers to activate the anti-collision bypass switch without the permission of the controller.

4.14 The evacuation of passengers was successfully coordinated by emergency services with the involvement of Veolia staff.

4.15 There was a delay in the incident notification to the OTSI and ITSR Duty Officers.

PART 5 RECOMMENDATIONS

To improve the safety of its monorail operations and prevent a reoccurrence of this type accident, it is recommended that the following remedial safety actions be undertaken by Veolia Transport Sydney.

5.1 Ensure that its drivers comply with the prescribed operating speeds for all sections of the track.

5.2 Ensure that its drivers understand the emergency braking system and are practised in its operation in periodic training drills.

5.3 Verify that the new Anti-Collision Control system ensures sufficient separation between monorails and does so under all operating conditions.

5.4 Finalise arrangements with the responsible authorities for the pruning or removal of vegetation which obscures track visibility within the “rail corridor”, particularly the tree presently obscuring sighting of the entrance into Darling Park Station from the City Centre Station approach.

5.5 Determine the cause of the monorail door failures and undertake whatever remedial action is necessary to ensure their consistent, reliable operation.

5.6 Ensure its track tape maintenance schedule provides for the timely inspection and replacement for worn tape.

5.7 Upgrade the audio recording system used for voice recordings between train control and drivers to ensure ease of retrieval and clear, high fidelity replay.

5.8 Ensure its monorail management system is capable of providing controllers with real-time data on the location of all monorails on the track.

5.9 Ensure all time logs on digital recording equipment are synchronised at all times.

5.10 Ensure the anti-collision bypass switch cannot be accessed by drivers without the permission of the controller.

5.11 Restrict the practice of allowing other persons to ride in the front cab with drivers, except in defined conditions of emergency, training or when only one monorail is operating on the track.

5.12 Develop and regularly conduct an emergency exercise that includes full participation by emergency services.

5.13 Ensure incident reporting procedures provide for the timely reporting of notifiable occurrences to OTSI and ITSR.

PART 6 APPENDICES

Appendix 1: Sources and Submissions

Sources of Information

- Bureau of Meteorology
- Independent Transport Safety Regulator
- Trantek Pty Ltd
- Veolia Transport Sydney Pty Ltd

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:

- Independent Transport Safety Regulator
- Metro Transport Sydney Pty Ltd
- Veolia Transport Sydney Pty Ltd

Submissions were received from all three 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.