

Emergency Public Address systems & Human Factors in Road Tunnels

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NZTA Queen Street, Auckland

8TH May 2019



Presentation

Part 1. Overview of recent Public Address System upgrades:
primarily Johnstone's Hill Tunnels and Victoria Park Tunnel

Part 2. Evacuation Messages and Human Factors

Q&A

New Zealand – NZTA major Road Tunnels - State of the Nation

- * Auckland – Waterview. 2017. Twin bored tube uni-directional. 3 lane. 2.4km . Motorway (urban). 80,000 ADDT
- * Auckland – Victoria Park. 2011. Single cut and cover uni-directional. 3 lane. 485m. Motorway (urban). 80,000 ADDT
- * Auckland - Johnstone's Hill. 2009. Twin tube mined uni-directional. 2 lane. 465m. Motorway (rural). 23,000 ADDT
- Wellington – Arras (memorial park). 2014. Single cut and cover unidirectional. 285m. State highway (urban). 20,000 ADDT
- * Wellington – Terrace. 1978. Single mined bidirectional . 2 lanes N, 1 South. 460m. State Highway (urban).47,000 ADDT
- * Wellington – Mount Victoria.1931. Single mined bidirectional. 1 lane each. 623m. State highway (urban). 45,000 ADDT
- * Lyttleton (Christchurch).1964. Single mined bidirectional. 1.6km.1 lane each. State highway from port.12,000 ADDT
- Homer (Fiordland).1954. Single mined bidirectional. 1.3km. One way. State highway to West Coast.< 2,000 ADDT

As at 2019 all long tunnels except Homer now have a deluge system as part of the tunnel fire life safety provisions (*)

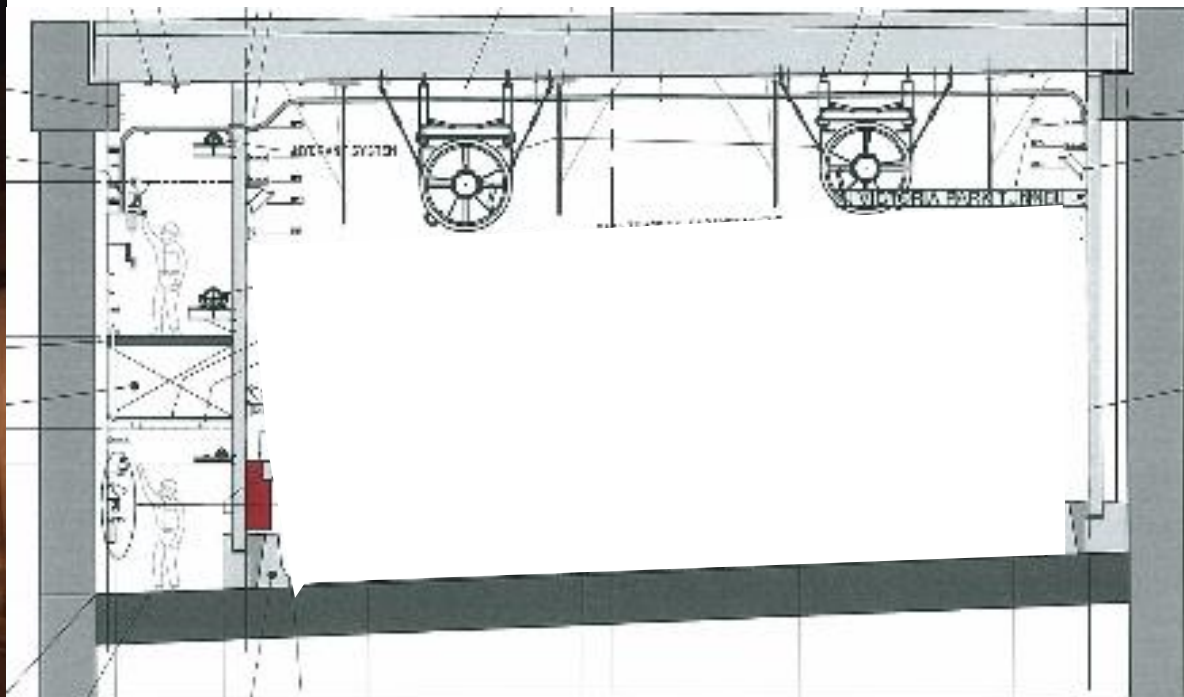
All tunnels have a PA system with Voice messaging as part of the Emergency Warning and Evacuation system, except Homer Tunnel which has PA at the Portal areas only

Public Address systems and Evacuation

- Voice Alarms as part of Emergency Warning (EWIS) over PA a core system and remains the case as best practice
- Part of the overall Fire Life Safety Design and Evacuation system design
- Recorded Voice messages allows Operators to attend to incidents quickly and carry out all other duties
- Free speech capability is also essential
- Needs good design and training

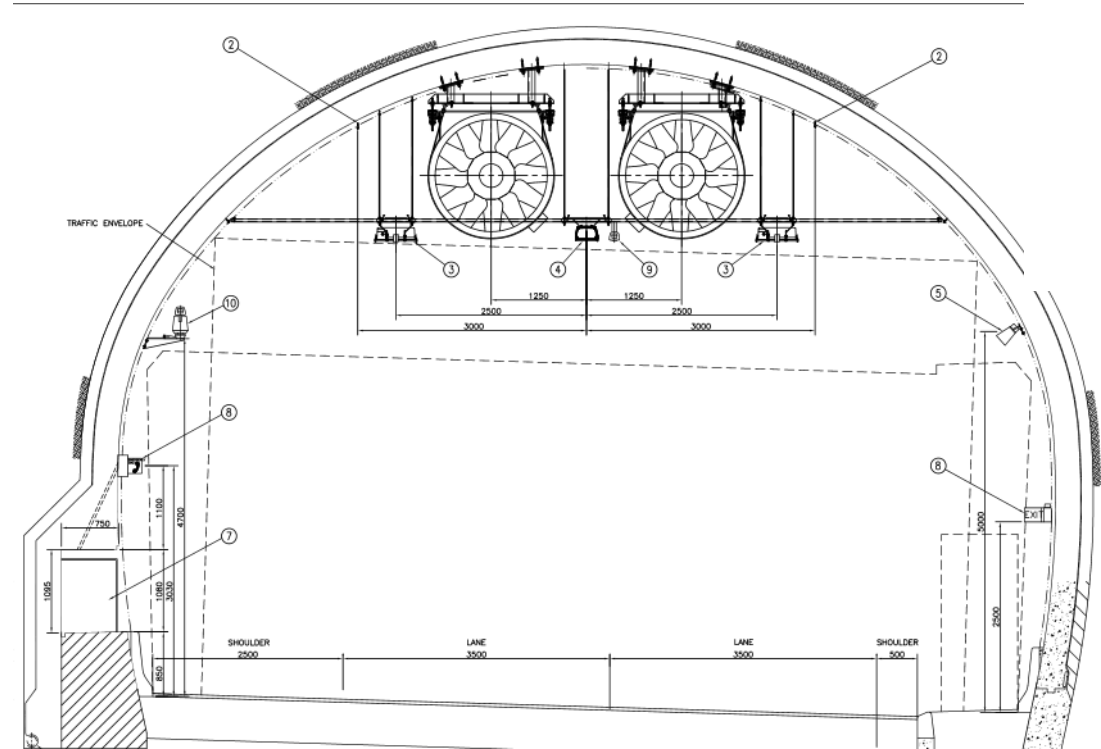


Public Address systems – Tunnels



Victoria Park Tunnel

Public Address systems – Tunnels



Johnstone's Hill Tunnels

Public Address systems – Tunnels



Waterview Tunnels



Lyttleton Tunnel

Public Address systems – Benchmarking 2016

Sound was highly reverberant.

Subjective intelligibility was also extremely poor.

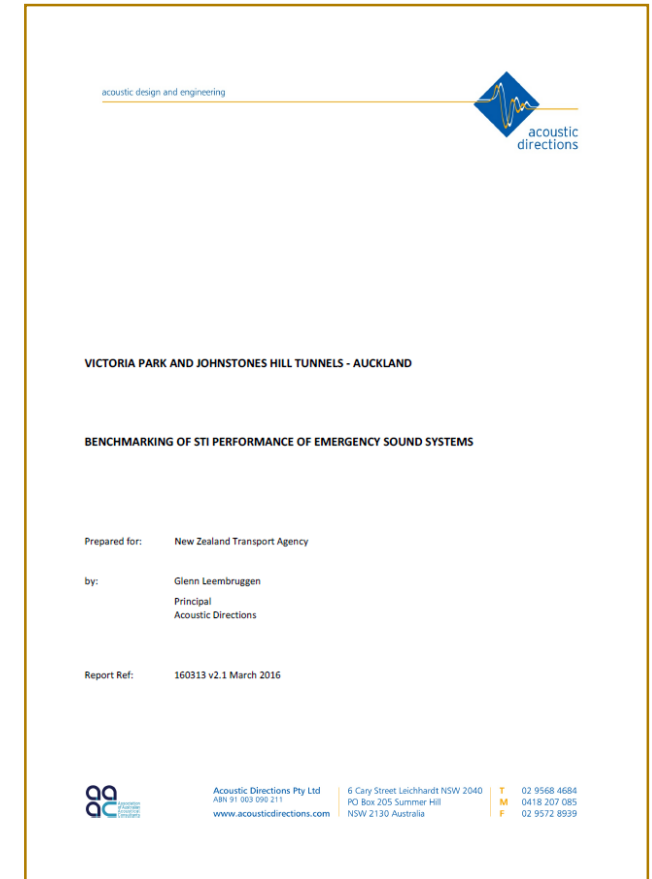
The tonal balance in the tunnel was extremely poor .

Simple messages were almost impossible to understand.

With the jet-fans running, the speech was not sufficiently loud to be audible

In a noise-free situation, the perceived intelligibility was substantially higher on one side of the tunnel than the other side (side mounted).

Tonal balance was coloured by high sound energy in the low mid frequency region (200 to 400 Hz).



Public Address systems – Benchmarking 2016

VPT – STI: Mean **0.26** < 0.36. Unacceptable

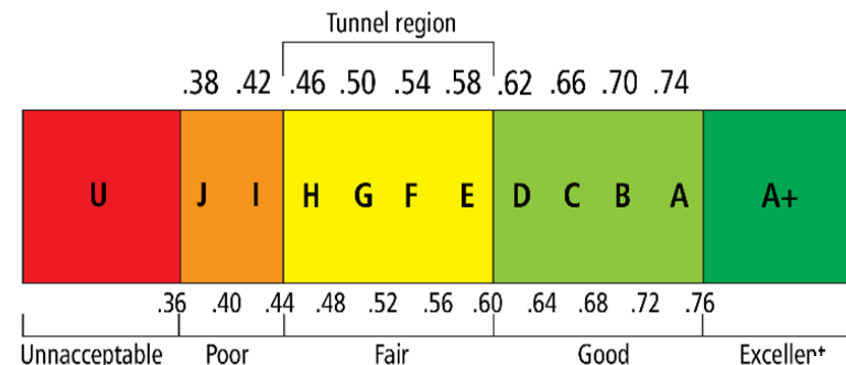
JHT – STI: Mean **0.09** < 0.36. Unacceptable

Above STI is without Noise

- Essentially not fit for purpose.
- Improvements could be made to the existing systems, with cost effective upgrades.
- Announcements should also be reviewed – recording quality, messages, selection of words and type were also a factor in poor STI levels, as well as information needed and inconsistency noted.

In general STI >0.5 is the expectation for Tunnels
Target set at >0.45

Intelligibility and Speech Transmission Index (STI)



Public Address systems – technical solution

- Technical solution was one we already knew a potential solution. Time delay, directional, flare speakers, Duran ABF-260 has been used successfully on other tunnels both in NZ and Aus.
- Others suppliers / systems of this type – but the Duran ABF had been the proven solution of choice in NZ
- No problems or issues seen with the head end equipment (Bosch)
- Retrofit solution - repurposing existing zones and minimising new cables and using existing head end equipment (Bosch Presidio) would achieve cost effective and practicable solutions with predicted $STI > 0.45$ (mean)
- 8 speakers at JHT (4 each tunnel)
- 16 speakers at VPT (8 pairs)
- Carried out over 18 months to reduce closure costs which are significant



AXYS Harmann
Duran ABF-260



Public Address systems – Results

Victoria Park

Parameter	System	Average	Std Dev
STI with noise	Previous	0.22	0.04
	Current	0.48	0.07
STI without noise	Previous	0.26	0.03
	Current	0.51	0.05
Speech L _{Aeq}	Previous	97.3	
	Current	93.5	1.2

Johnstone's Hill

Parameter	System	Average	Std Dev
STI with noise	Previous	0.09	0.017
	Current	0.38	0.05
STI without noise	Previous	0.09	0.07
	Current	0.45	0.05
Speech L _{Aeq}	Previous	83.1	
	Current	92.0	1.5

- The tables compare the STI and level results of the previous and new systems for VPT and JHT.
- The new systems in both tunnels have produced a vast improvement in the STI performance, both with and without noise.

Public Address systems – Comparison

Victoria Park			
VPT	STI-with noise	STI-without noise	Speech L _{Aeq}
Average	0.48	0.51	93.5
Std Dev	0.07	0.05	1.19
Mean-1 x SD	0.41		

Johnstones Hill			
Pos No	STI-with noise	STI-without noise	Speech L _{Aeq}
Average	0.38	0.45	92.0
Std Dev	0.05	0.05	1.5
Mean-1 x SD	0.32		

Lyttelton			
VPT	STI-with noise	STI-without noise	Speech L _{Aeq}
Average	0.37	0.51	98.4
Std Dev	0.03	0.03	1.0
Mean-1 x SD	0.34		

Waterview			
Pos No	STI-with noise	STI-without noise	Speech L _{Aeq}
Average	0.44	0.52	96.2
Std Dev	0.05	0.04	1.5
Mean-1 x SD	0.39		

Average and standard deviation of STI results with and without noise and the average operating speech level. (Noting Jet-fan noise is often highly variable along the tunnel).

Lyttelton

- 13 sec reverberation times below 1000 Hz!
- Low ventilation noise
- High specified traffic noise of 92 dBA everywhere

Waterview

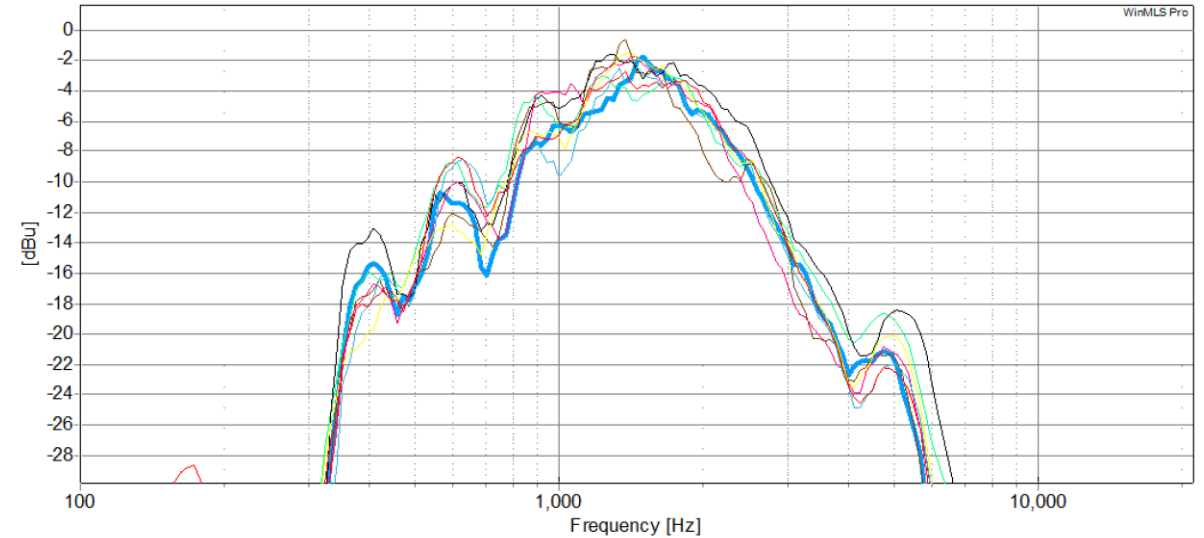
- Jet fan noise ranges from 93 dBA to 72 dBA (Note – system has used DHN Tunnel500/DUP-4 speakers)

Public Address systems – frequency response

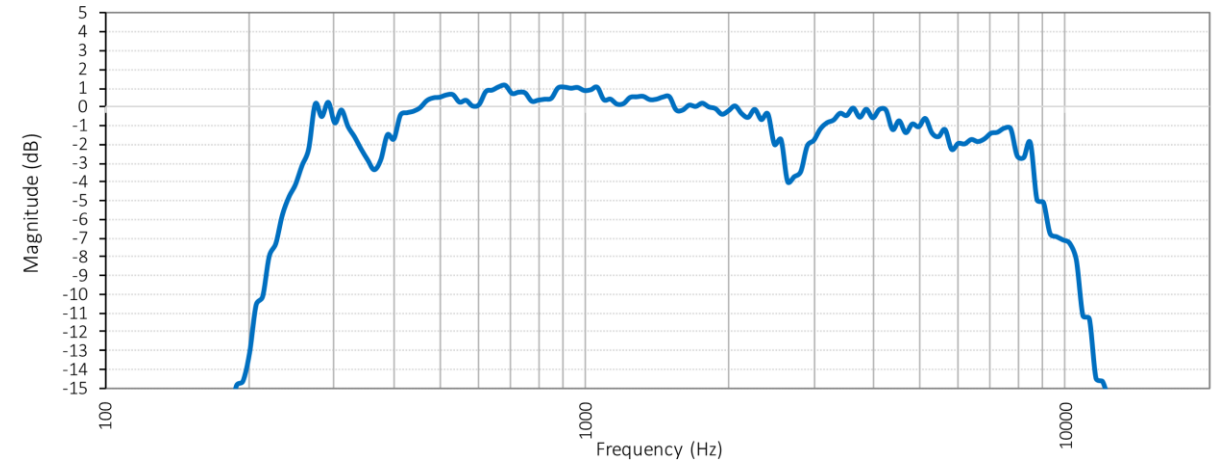
- The troughs at 360 Hz and 2.7 kHz are due to phase cancellation effects. They could have been removed through equalisation, but the tonality of the sound was noticeably poorer when they were “filled in”.
- The gentle overall downward slope was introduced to make the speech more comfortable to listen to at high sound levels.

C/O Acoustic Directions – VPT Report

Existing system

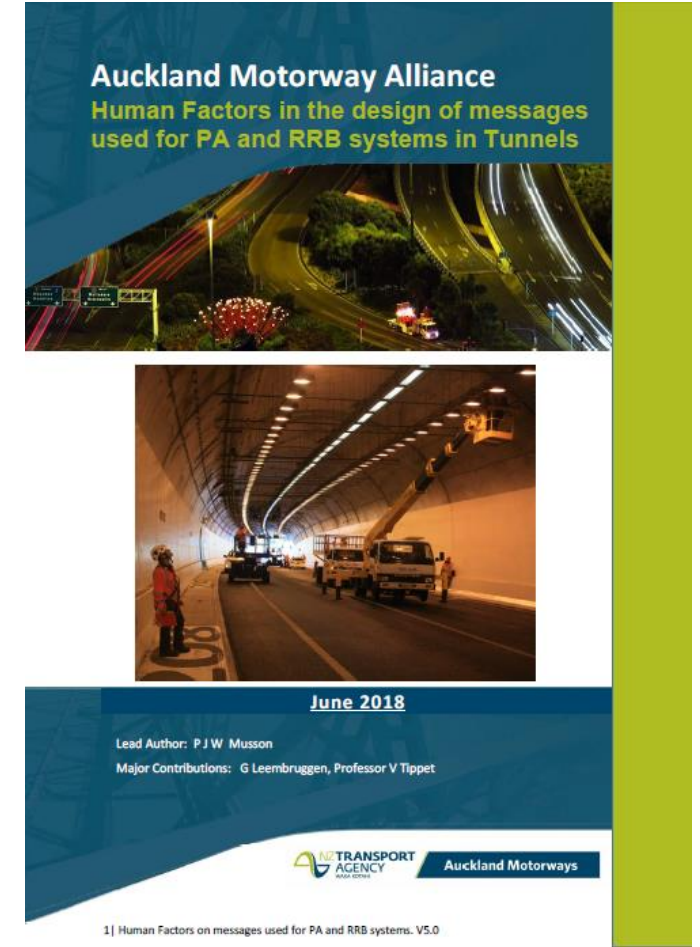


New system



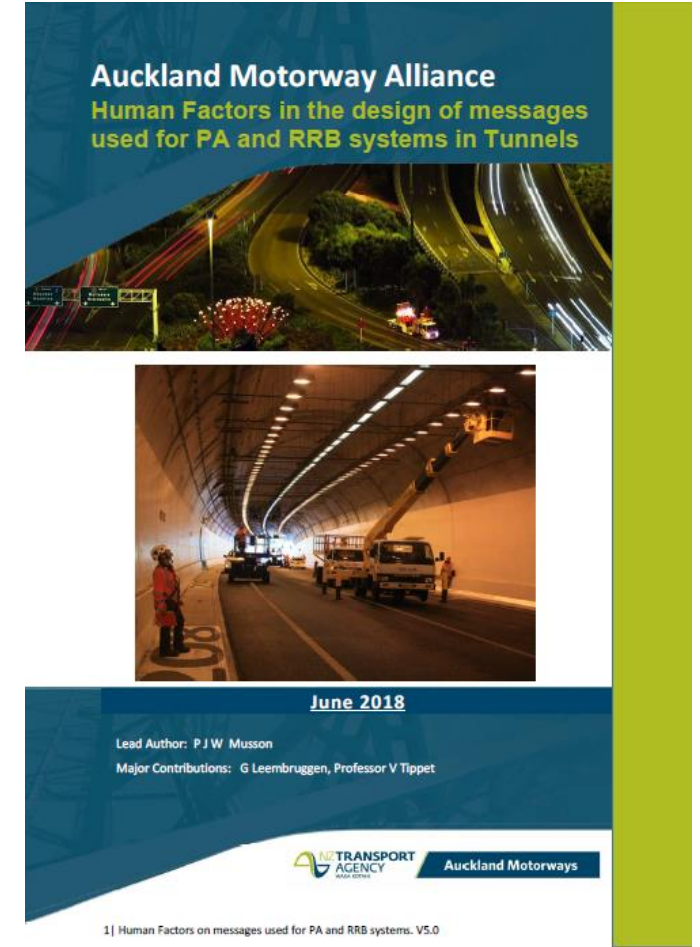
Public Address systems – Message announcement study

- Part 2 – Evacuation Messages and Human Factors



Public Address systems – Message announcement study

- Progressed during upgrades
- Not a full research study- limited funds
- No user testing survey prior or after
- Acoustic Directions, NZTA Tunnel Managers, NZTA acoustic advisors
- Peer Review by Professor Vivienne Tippet (Queensland University of Technology) –for the proposed message structure and message wording, linguistics, and literature research on evacuation messages.
- Now circulated to ATOG, PIARC Tech committee and others



Public Address systems – Messages

- Different tunnels had different messages – often taken from last tunnel, no real consistency
- No separate evacuation messages for incident type
- PA or PA/RRB
- Gaps in information being provided to public
- More advisory messages could be used

Examples of existing Primary evacuation message over PA

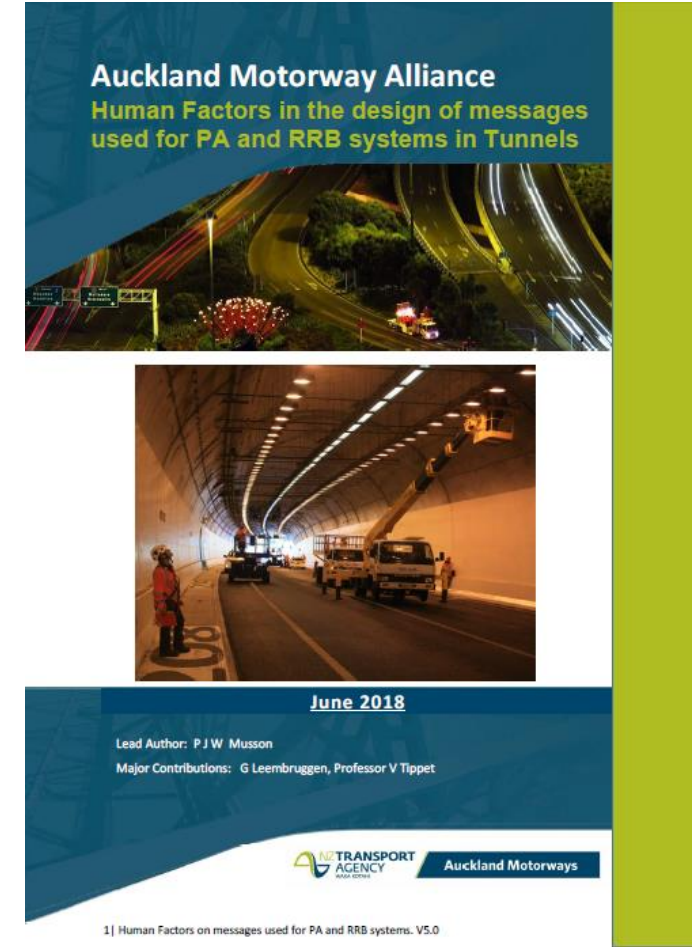
Evacuate the tunnel....turn off your engine and leave your car

Evacuate the tunnel...use the nearest Exit

Evacuate the tunnel. Turn off your engine, leave your vehicle and head to the emergency exits

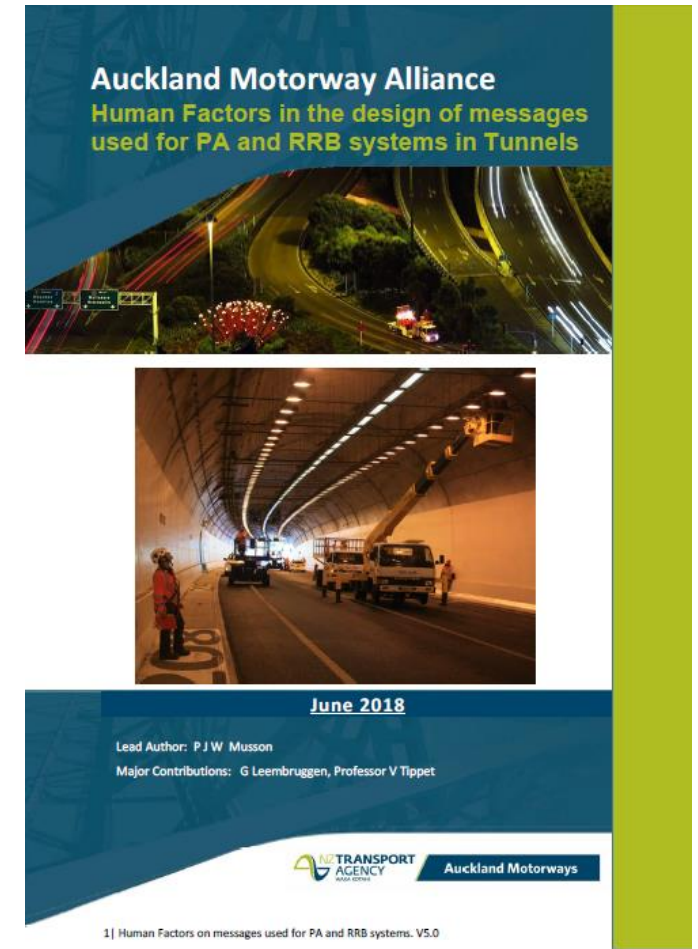
Attention, attention, the fire alarms are sounding. Evacuate by the nearest exit immediately

Emergency, Emergency....Evacuate Tunnel Now



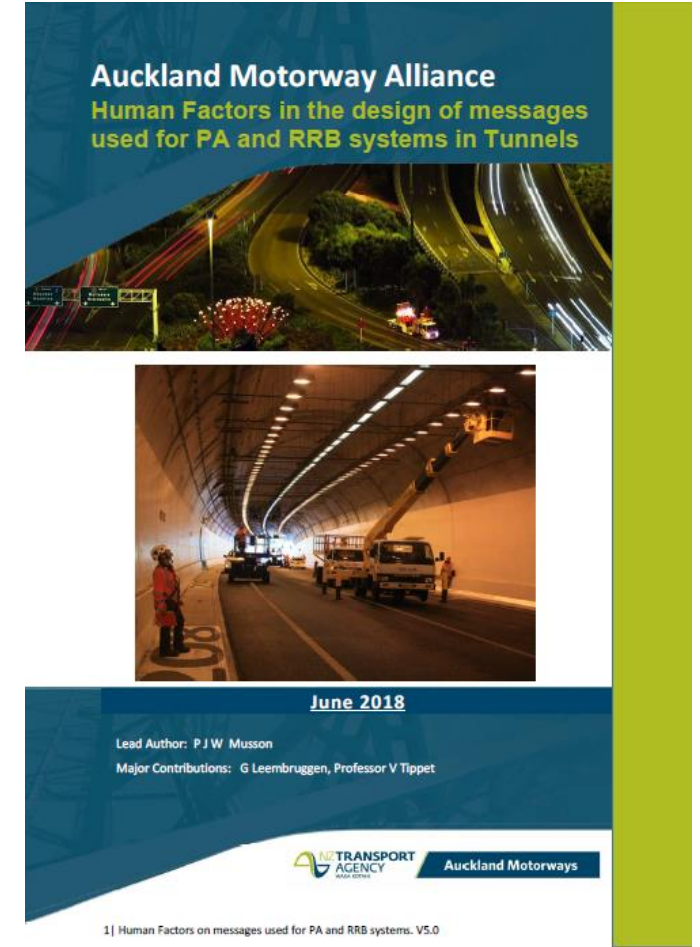
Public Address systems – Standards

- NZS4512 (currently 2010) –Fire Detection and Alarm Systems
- AS 1851(currently 2012) - Routine service of fire protection systems and equipment
- AS1670 PART 4; (current 2004) - Fire detection, warning, control and intercom systems- system design, installation and commissioning. Part 4 - Sound Systems and intercom systems for emergency purposes
- AS 60849:2004– Sound systems for emergency purposes (IEC 60849:1998 MOD)
- AS 2220- Emergency warning and intercommunication systems in buildings
- ISO 8210 - Alarm systems - Audible emergency evacuation signal – Requirements
- Standard IEC 60268-16 2011 on acoustic testing STI



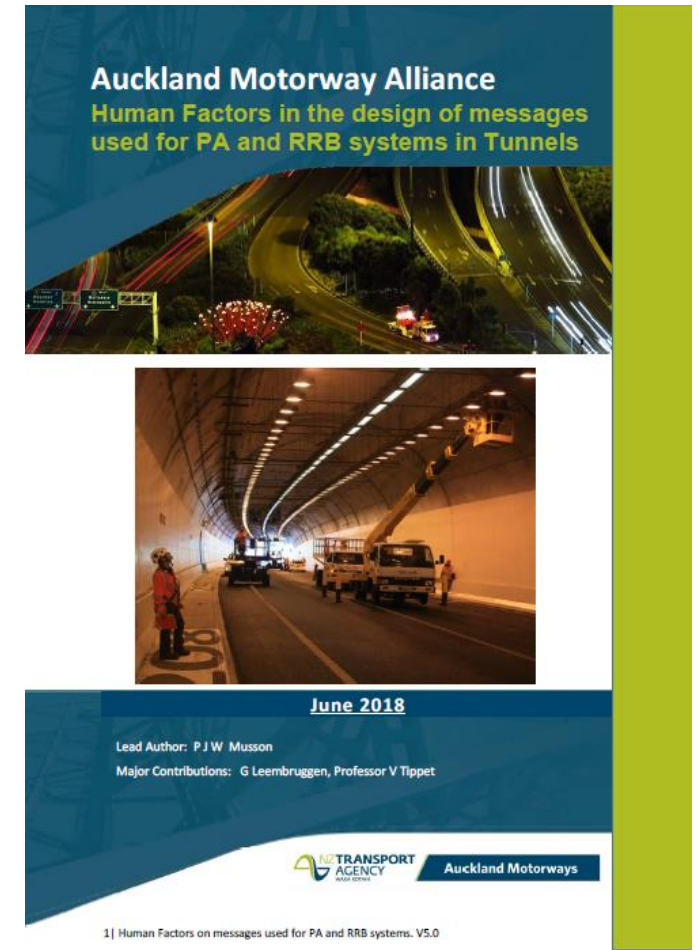
Public Address systems – Guidance

- Austroads Guide To Road Tunnels – and NZTA Supplement to Austroads Guide to Road tunnels Dec 2013
- PIARC- 2008R17 Human Factors and Road Tunnel Safety Regarding Users, PIARC Technical Committee C3.3 Road Tunnel Operation,
- BS8839-8(2008) and BS58392- Fire Detection and alarm systems PART 8 – COP for voice alarm systems
- NFPA 72
- EN-54-16 (2008) and IS07240-16



Public Address systems – Summary

- There are few specific guidance requirements on the **design and recording** of the messages, (nor the mandatory requirement to achieve set STI levels relating to speech intelligibility) in NZ.
- There is also little guidance requirements for message providers on the **actual content**, other than the use of 3 key words from fire alarm standards, and 3 basic level of priorities.
- In general, mention is sometimes made of the components of message delivery, including the manner in which messages should be delivered but are qualitative and not defined (e.g. clear, concise and in a calm and authoritative manner). The need for intelligibility, some advice on message duration, and the importance of an alert tone referred to.
- Standards and Guidance focus is thus primarily on the technical function of the systems, with an overarching philosophy on operational function and performance for messages.



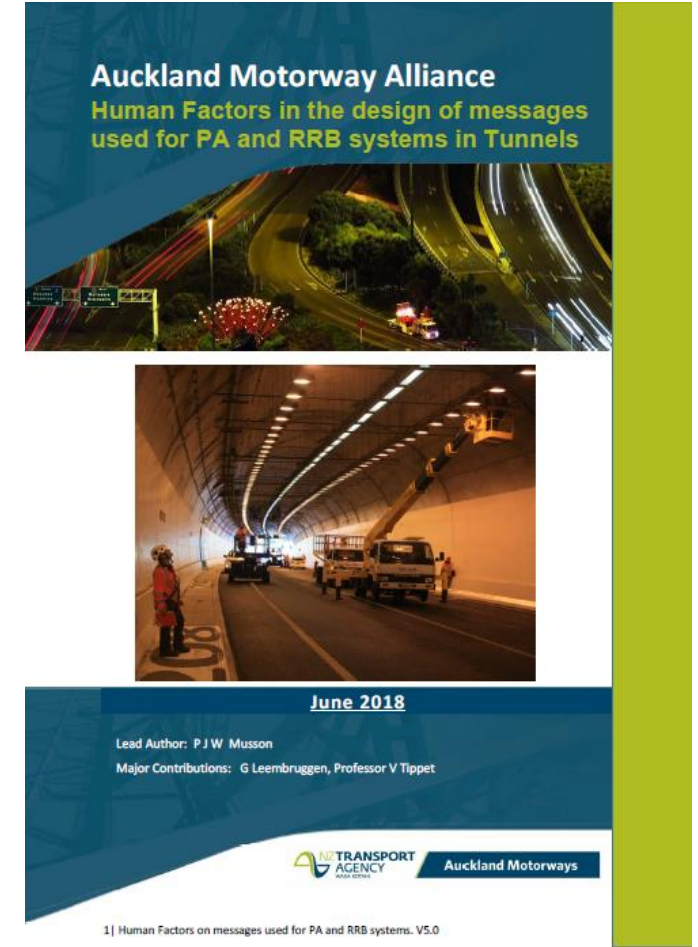
Public Address systems – Message structure and content

Content and structure had been looked at and studied by others more recently:

- Kuligowski et al. NIST Technical Note 1827 (2014),

Dr. Erica D. Kuligowski - sociologist in the Wildland-Urban Interface(WUI) Fire Group of the Fire Research Division (FRD) of the Engineering Laboratory(EL) at the National Institute of Standards and Technology (NIST) in the USA. Expertise in evacuation and response behaviour, people movement and behavioural data collection and analysis from fires. Study and work (2012 - 2017), has been subsequently incorporated, developed and peer reviewed by various other reputable fire safety bodies, such as the NFPA and SFPE, and has been cited and referenced.

- Higgins et. al. (2015), Omore et. al. (2017), Isherwood et. al. (2016), Song et. al. (2016) , Burns et. al. (2015), Nillson et. al.(2017), Rhonchi et. al. (2016).



Public Address systems – Message Structure

Messages shall use three basic categories of message (purpose):

- **Emergency** (evacuation) - urgent priority message for evacuation and immediate response messages only – some of which will be automatically triggered by the Tunnel Fire Alarm pane. This should be repeated in any message.
- **Warning** (alert)– next level priority - warning of hazards and danger or caution
- **Attention** (advisory) - information messages or all other messages not covered above

Public Address systems – Message Structure

- For the primary Evacuation messages initiated by the fire alarm systems, they should comply with NZ4512 and be preceded by the “4 bust square wave tone” (NZS4512).
- The maximum duration of the message (excluding alert tone) shall be around 20 seconds (NZ4512).(note this has been exceeded - to 27 seconds in some cases)
- The message shall contain the words “Emergency” and “Fire”, (NZS4512), and “Evacuate now” (AS 1850).

The message structure shall be in the form:

[Who is making the Message]

[What’s happening / purpose]

[Where it is] [The risk / why they need to do it]

[Primary what they should do} [when to action]

[Secondary what to do]

Public Address systems – messages – fire evacuation

4 burst Alarm Tone.

“This is the Tunnel control room; Emergency, Emergency. There is a fire in the tunnel; you are in immediate danger from smoke. Evacuate the tunnel now; Turn off your engine, leave your vehicle and go immediately to the nearest Emergency Exit or outside the tunnel”

45 words, 18 seconds alert tone, 27 seconds message, Flesh-Kincaid Reading Grade 6.6

[Who is making the Message]

[What's happening / purpose]

[Where it is] [The risk / why they need to do it]

[Primary what they should do] [when to action]

[Secondary what to do]

Compared to an existing message.

Alarm tone “Evacuate tunnel...use nearest Exit”

Play Message



Public Address systems – new messages

- Suite of 29 messages recorded . Some being variants for specific tunnels .
- “A Toolkit ” and choice for use in Operations
- PA only, PA/RRB, RRB only
- 12 Emergency
- 9 Warning
- 8 Advisory

Message Ref	Type	Scenario / rationale	Announcement
Major Incident / Emergency			
E1**	Fire - Tunnel	Vehicle fire in tunnel requiring immediate closure of the tunnel and immediate public evacuation of tunnel. This is the primary evacuation message and needs to get the public out of their cars and moving to exits as soon as possible.	4 Bust Tone This is the Tunnel control room; Emergency, Emergency. There is a fire in the tunnel; you are in immediate danger from smoke. Evacuate the tunnel now; Turn off your engine, leave your vehicle and go immediately to the nearest Emergency Exit or outside the tunnel.
E2**	Hazardous spill- Tunnel	Incident / accident and observed or reported hazardous spill (but no fire) in the tunnel by operators, requiring immediate closure of the tunnel and immediate public evacuation. As E1 it is important to get people out of cars and moving to exits as soon as possible.	4 Bust Tone This is the Tunnel control room. Emergency, Emergency. There is a spill of dangerous material in the tunnel; you are in immediate danger from fumes. Evacuate the tunnel now; Turn off your engine, leave your vehicle and go immediately to the nearest Emergency Exit or outside the tunnel.
E3**	Fire - non tunnel area - staff	Some tunnels have back of house ancillary areas. The fire alarm would alert staff in these areas and not automatically close tunnel or initiate tunnel public evacuation. Staff would need to evacuate until investigated. Operators would decide if to close tunnel and if needed, then tunnel evacuation would be declared and E1 would then be broadcast in tunnel	4 Bust Tone This is the control room; Emergency, Emergency; Fire has been detected in the Building; you are in immediate danger from smoke. Evacuate the building now; Leave by the nearest emergency exit. Go to the assembly point now.
E4**	Fire - Tunnel	As E1 but specific for tunnels with no cross passages / side egress and directional lights - the only way out is to the portals	4 Bust Tone This is the Tunnel control room; Emergency, Emergency. There is a fire in the tunnel; you are in immediate danger from smoke. Evacuate the tunnel now; Turn off your engine, leave your vehicle, and follow the directional lights and signs to outside the tunnel.

Public Address systems – new messages

Warning

This is the Control Room; Warning Warning. There is heavy traffic in the tunnel, vehicles are queuing. Slow down now. Drive with caution and prepare to stop. If you have to stop, turn off your engine and wait for traffic to move again. Do not leave your vehicle.



Play Message

Advisory

This is a Safety message from the Control Room. The speed limit in the tunnel is 50. Do not overtake in the tunnel and keep a safe distance between vehicles



Play Message

Public Address systems – recording messages

- Little published detailed guidance or standards on how messages should be recorded to give optimal outcomes
- Developed a standard Specification for the selection of artist and recording of voice messages for PA / RRB systems
- The new messages recorded by Big Mouth (Voice Agency), Auckland, using voice artist previously used and assessed, overseen and post processing work by Acoustic Directions.
- The recording covers an in perpetuity licence for usage of messages in NZ



Public Address systems – recording messages

SELECTION OF VOICE ARTIST

The voice artist shall be selected according to the following parameters:

- Mature female adult, (not young adult).
- Ability to speak very slowly but naturally. The speech rate for messages shall be around 127 words per minute. Different speaking rates may be required for tunnel PA messages and RRB messages, with tunnel messages requiring possibly as low as 115 words per minute to allow for reverberation in the tunnel.
- Authoritative sound, but friendly and trustworthy.
- Vocal tonal content that is not ultra-bright (i.e. not too strong on the “ess” components of words) chesty or husky. Some “edge” to the voice from upper harmonics is required without the voice sounding “nasal”.
- The accent shall be neutral (NZ), but not a strong (NZ) accent.
- Ability to work collaboratively with the acoustic engineer using a number of takes to achieve the optimum delivery-rate and annunciation.
- The consistent use of previous engaged voice-artist is desired for consistency.

Public Address systems – recording messages

RECORDING PROCESS

- Messages shall be recording with a relatively bland speaking style with some authority, without strong emphasis or expression that is usually used for storytelling.
- The recording must be made in a relatively “dead” or “dry” acoustic environment, with a high degree of acoustic absorption located near the artist and microphone.
- Recordings in a small voice-booth may be unsuitable due to acoustic resonances in the booth, which are generally difficult to control.
- The microphone should be located at least 2 m from a wall with the voice artist facing away from the closest wall.
- The recording studio shall provide the facility to allow remote listening to the recording session by NZTA’s representative including interactions with the artist and recording engineer.
- Microphone filters shall be used to eliminate audible breathiness in the speech or popping with plosive phonemes; e.g., “p” and “b” sounds.
- The microphone used for the recording shall be a high-quality type condenser type intended for professional use. The microphone shall have a frequency response better than ± 1.5 Db over the range 100 Hz to 12 kHz, when measured on axis at a distance of 300 mm. Shotgun microphones shall not be used.
- Audio limiting or compression shall not be applied to the voice during the recording process or the recorded signal.

Public Address systems – recording messages

DIGITAL RECORDING AND STORAGE

The ambient noise level in the recording studio shall be less than 30 dBA, and free of noticeable hum or buzz.

The signal to noise ratio of the electronic recording chain shall exceed 60 dB (lin) re 0 dBFS

The peak level of the recorded signal should lie between -6 dBFS and – 1 dBFS.

Messages shall be recorded at 44.1 kHz sampling rate with a bit depth of 16 bits.

Messages shall be stored and archived in .wav format. The use of digital compression techniques to reduce the file size and bit rate is not permitted.

Public Address systems – recording messages

AUDIO PROCESSING OF MESSAGES

Listen critically to the recordings on a set of studio monitor loudspeaker and apply the following signal processing if necessary:

- Elongation or shortening of gaps between syllables or words.
- De-essing of excessive sibilance
- High pass filtering to suit the tunnel loudspeaker's bandwidth
- Narrow-band filtering to remove colouration from room resonances or room build-up at low frequencies in the studio.
- Matching of the long-term RMS level of each announcement according to the standard BS1770.
- Adding a small amount of “bite” to the sound to enhance clarity.

Public Address systems – validation and roll out

- Used at Lyttleton in upgrades
- Like for like swap at JHT & VPT (until review of HMI) – fully optimisation in March 2019
- Progressive move over on other tunnels over time
- Emergency exercises
- Other feedback
- Further expansion of work and research in this area