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24 December 2020

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SYDNEY METRO CHATSWOOD TO SYDENHAM (SSI 15_7400)
Track Attenuation and Operational Ground-borne Noise Review (Condition D9)

This letter documents the findings of the first part of my independent review of the proposed design objectives and track attenuation for ground-borne noise, in accordance with Condition D9 of planning approval SSI 15-7400.

The full text of the condition is included at Annex A to this letter while Annex B attaches DPIE's approval of my role as Sydney Metro's nominated ground-borne noise specialist. My curriculum vitae is attached at Annex C.

1 Scope

The scope of this letter addresses the two sections of the Sydney Metro tunnels where track installation is scheduled to be completed first. These sections are:

1. From the Chatswood Dive to the northern end of Crows Nest station, and
2. From the southern end of Waterloo station to the Marrickville Dive.

The scope of my review of these sections encompasses part (a) of Condition D9, which requires that I review "the appropriateness of the proposed design (noise) objectives for ground-borne noise sensitive receivers" and part (b) of Condition D9, which requires my review of ground-borne noise predictions to "confirm the appropriate track attenuation required" to meet the objectives in part (a).

The condition requires that the review is submitted to the Secretary at least one month prior to the installation of track.

Condition D9 refers specifically to ground-borne noise but I have also considered ground-borne vibration as part of this review. Ground-borne noise and ground-borne vibration are generated from the same source (the operation of trains on track) and the selection of track attenuation treatments must consider both effects.

2 Relevant background

Sydney Metro submitted the State Significant Infrastructure Application Report for the Chatswood to Sydenham project in November 2015. The Department of Planning, Industry and Environment (DPIE, formerly the Department of Planning and Environment) provided the Secretary's Environmental Assessment Requirements (SEARs[1]) in December 2015. This listed noise and vibration amongst the key issues and requested assessment in accordance with established Environment Protection Authority (EPA) guidelines.

Sydney Metro submitted the Environmental Impact Statement (EIS) in 2016 and it was exhibited by DPIE during May and June 2016. The EPA's submission noted that the EIS demonstrated "the project can be built such that noise and vibration does not exceed relevant criteria" and recommended that approval conditions include compliance with the Rail Infrastructure Noise Guideline (RING)[2] and Assessing Vibration: A Technical Guideline (AVTG)[3].

The project was granted approval[4] in January 2017. The accompanying Secretary's Environmental Assessment Report[5] noted that it had been designed to meet appropriate ground-borne noise design objectives derived from RING and was satisfied that this was achievable based on other operational rail tunnels. However, DPIE was concerned that:

- the assumptions used to predict ground-borne noise were based on theoretical and not actual geological conditions along the alignment; and
- the design objectives adopted for some sensitive receivers may not be appropriate. For example, it may be more appropriate that particularly sensitive receivers such as religious buildings, surgeries and acoustically designed halls and studios have more stringent design objectives than proposed.

DPIE therefore recommended an independent review of the proposed ground-borne noise design objectives and the ground-borne noise and vibration model to ensure that appropriate objectives are identified and met with sufficient track attenuation. This review is specified in Condition D9 of the approval (attached at Annex A.)

3 Methodology

I have carried out my review of the design objectives by:

- checking that the criteria in the SEARs[1] have been adopted correctly;
- verifying that these criteria are appropriate by comparing them against overseas guidelines where available; and
- ensuring that the specific requirements of particularly sensitive receivers have been addressed.

I have visited some of the particularly sensitive receivers to understand their facilities and the nature of their noise and vibration sensitive activities.

My review of the ground-borne noise predictions and track attenuation design has focused on the detailed predictions carried out by Sydney Metro's design consultant, Metron. The prediction results and track attenuation

[1] Secretary's Environmental Assessment Requirements, DPIE 2015
[2] Rail Infrastructure Noise Guideline, NSW EPA 2013
[3] Assessing Vibration: A Technical Guideline, NSW EPA 2006
[4] Approval Instrument, Sydney Metro City & SouthWest: Chatswood to Sydenham, SSI 7400, DPIE 2017
[5] Secretary's Environmental Assessment Report, DPIE 2017

details are presented in the Sydney Metro Acoustic Assurance Tool, an interactive GIS portal that shows the inputs, assumptions and outputs of the prediction model for each receiver location near the tunnels.

I have also considered the noise and vibration performance of Sydney Metro NorthWest, which has been operating since May 2019. This line includes tunnels that are located close to residential receivers and operates the same rolling stock and some of the same track forms as those that will be used on the Chatswood to Sydenham line.

4 Review of Design Objectives

4.1 Residential Receivers

Ground-borne Noise

The EIS adopted the ground-borne noise trigger levels from RING[2], namely 40dB$L_{Amax,S95\%}$ for daytime and 35dB$L_{Amax,S95\%}$ for night time. The night-time criterion is more stringent than the daytime criterion and is therefore the controlling factor for residential receivers.

I consider that the RING criteria are appropriate for this project, taking into account the following:

- The criteria are consistent with the requirements of the SEARs[1] and noted to be appropriate in the Secretary's report[5].
- Page 13 of the guideline states that *"Levels of 35–40 dB LAmax are [..] typically applied and likely to be sufficient for most urban residential situations, even where there are large numbers of pass-by events" and [The trigger levels] "are necessarily set to the lower end of the range of possible trigger values so that potential impacts on quieter suburban locations are addressed. In practice, higher levels of ground-borne noise than the trigger level for assessing impacts may be appropriate for urban areas where background noise levels are relatively high."*
- On the face of it, the 35dBA design objective is consistent with overseas criteria, such as US FTA impact assessment manual[6] (Table 6-3) and comparable projects in the UK, such as CrossRail, which applied a criterion of 40dBA[7], but with an additional requirement to use reasonable endeavours to further reduce ground-borne noise levels to 35dBA. The RIVAS project noted ground-borne noise target values in Europe of 38dBA and 48dBA (depending on location)[8].
- In practice, the RING guideline differs from overseas criteria because it applies the design target to 95% of trains so that the maintenance condition of trains is also addressed. This requirement is primarily dealt with via maintenance (particularly wheel tread condition) but it also requires more conservatism in the track attenuation design than required by other jurisdictions.

On this basis I consider that the design objectives for ground-borne noise at residential receivers are consistent with, or more stringent than, the approach used on comparable projects in Europe and North America. Overall, I consider these design objectives are appropriate.

Ground-borne Vibration

The EIS adopted the vibration criteria in EPA's Assessing Vibration: A Technical Guideline (AVTG)[3], which sets goals in terms of the Vibration Dose Value (VDV) for daytime and night-time periods. However, the EIS also adopted an

[6] Transit Noise and Vibration Impact Assessment Manual, FTA Report No. 0123, 2018
[7] Crossrail Information Paper D10 – Groundborne Noise and Vibration, Crossrail 2008
[8] Railway Induced Vibration: State of the art report, UIC 2017 (section 5.2)

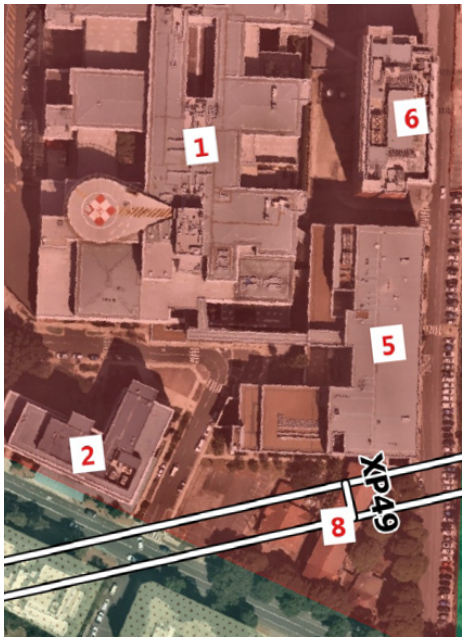
approach based on overall vibration velocity levels; these levels a more conservative than the VDV goals but were used in the EIS as a screening criterion, noting that ground-borne noise (rather than ground-borne vibration) generally controls the outcome from new rail tunnel projects.

The vibration velocity goals adopted in the EIS are 106dBV (0.2mm/s) for daytime and 103dBV (0.14mm/s) for night-time (maximum rms, 1 second). As with ground-borne noise, the night-time criterion is more stringent than the daytime criterion and is therefore the controlling factor for residential receivers. The goal of 103dBV (0.14mm/s) is more stringent than the VDV goal applicable under the EPA guideline and is close to the threshold of human perception. On that basis, I consider that compliance with the goal of 103dBV (0.14mm/s) represents a very good standard and goes beyond AVTG requirements. I am satisfied that this approach will achieve compliance with the guidelines.

4.2 Other Sensitive Receivers

The Secretary's Report[5] highlighted the need to review the design objectives for "Particularly sensitive receivers such as religious, surgeries, acoustically designed halls and studios".

For the purpose of my review, I have also included medical facilities as these may contain vibration-sensitive equipment. There are 3 relevant receivers near the sections of the tunnels considered in this review: the Royal North Shore Hospital campus, St Leonards; MedLab, 66 McCauley Street, Alexandria; and Stage Door Productions, 33 Maddox Street Alexandria.



Royal North Shore Hospital

The figure to the right is an extract from the hospital map showing the alignment of the Sydney Metro tunnels and the hospital buildings closest to the tunnels.

The numbered buildings shown on the map are: 1) Acute Services Building (ASB), 2) Community Health Centre, 5) Clinical Services Building (CSB), 6) Kolling Institute, 8) Herbert Street Clinic. (Note: buildings 3, 4 and 7 are further from the tunnels).

The metro tunnels are shown in white and "XP49" shows the location of cross passage 49, directly below the Herbert Street Clinic.

I visited the hospital several times in May and June 2019 to meet with staff during tunnelling and cross passage excavation works.

The table on the next page shows the ground-borne noise and vibration sensitivity of these facilities, the criteria proposed by Sydney Metro and my assessment of whether these are appropriate.

Building	Ground-borne noise sensitivity	Criteria proposed by Sydney Metro ($dBL_{Amax,S95\%}$)	My assessment	Ground-borne vibration sensitivity	Criteria proposed by Sydney Metro	My assessment
1 (ASB)	Patient wards (Note 1)	35	Appropriate	Sensitive equipment	Note 2	Appropriate
2	Medical facility	40 - 45	Appropriate	Human comfort	103dBV	Appropriate
5 (CSB)	Patient wards	35	Appropriate	Human comfort	103dBV	Appropriate
6	Medical facility	40 - 45	Appropriate	Sensitive equipment	Note 2	Appropriate
8	Patient wards	35	Appropriate	Human comfort	103dBV	Appropriate

Note 1: The EIS assessed patient wards by applying the residential criteria in RING[2]

Note 2: The EIS adopted a screening criterion of Vibration Criterion (VC) Curve C for sensitive equipment at medical facilities. Having visited the facility I consider that this is appropriate. I also note that tunnelling and cross passage excavation activities generate significantly higher vibration levels than future train operations and I understand that there were no vibration impacts on sensitive equipment during construction.

MedLab

This biotechnology laboratory facility includes a number of microscopes with up to 1000x magnification. The EIS adopted a screening criterion of Vibration Criterion (VC) Curve C for such facilities. This is appropriate, although the FTA guide also notes that the VC-B curve, which is less stringent than VC-C, is acceptable.

Stage Door Productions

This facility provides rehearsal space for bands and amplified music. It also carries out recording on some occasions, which means it is potentially sensitive to ground-borne noise. The EIS adopted a ground-borne noise design goal of NR15 (equivalent to approximately 20dBA) for recording studios, although I note that this was also intended to cover more sensitive facilities such as broadcast facilities and spaces used for recording unamplified sound. Sydney Metro proposes to apply the EIS design goal for drama theatres, NR25 (equivalent to approximately 30dBA), and I consider that this is appropriate in this case.

4.3 Findings

I have reviewed the proposed design objectives for ground-borne noise sensitive receivers (including residential receivers) near the two sections of tunnel addressed in this letter. I consider that the proposed design objectives are appropriate.

5 Review of Predicted Impacts and Track Attenuation

5.1 Modelling

At the EIS stage, ground-borne noise and vibration was predicted using an empirical model, based on assumptions about geotechnical conditions. It was also based on source vibration levels for Sydney Trains rolling stock, because Sydney Metro rolling stock was not yet in operation at that time.

The prediction model used for the final design has progressed significantly since the EIS. In particular:

- The MOTIV[9] model has been used to predict vibration levels close to the track and to assess the effects of geotechnical conditions, including the way vibration propagation is affected by soil layers;
- The MOTIV source vibration predictions have been validated against measurements of actual operational vibration from Sydney Metro NorthWest;
- Assumptions about geotechnical conditions have been updated with detailed information obtained during the tunnelling stage;
- Similarly, assumptions about the buildings surrounding the tunnels have been updated based on detailed information about structures and foundations (obtained for the tunnelling stage) and from the extensive community and stakeholder engagement process carried out during construction.

I have reviewed the modelling approach and the assumptions used and I consider them appropriate. I note that the source vibration levels used in the modelling are similar to those assumed in the EIS, but measurement data from actual operational vibration from Sydney Metro NorthWest indicates that these source levels are conservative. I also note that conservative assumptions have been made about the vibration response of buildings and the radiation of ground-borne noise. These conservative assumptions effectively build in a safety factor in the predictions, in addition to that specifically included in the calculation process.

I have also reviewed the operational performance of Sydney Metro NorthWest. There have been some complaints about noise from this line, but these relate to PA announcements at stations, horn noise near Chatswood and noise levels inside the trains. However, I understand from Sydney Metro that there have been no complaints about ground-borne noise and vibration. The operator carried out measurements at a number of receiver locations close to the tunnels in 2019 and confirmed compliance with the ground-borne noise and vibration design goals.

On this basis I am satisfied that the predicted impacts of ground-borne noise and vibration have been appropriately assessed.

5.2 Track Attenuation Design Evolution

The EIS assumed three levels of track attenuation: standard, high and very high. Based on the modelling carried out at that time, the EIS concluded that standard track attenuation would be sufficient for around 90% of the alignment but recommended high track attenuation for around 8% of the alignment and very high attenuation for the remaining 1 or 2%.

Sydney Metro's final design for track attenuation adopts the very high attenuation system for the majority of the alignment, which means that the outcomes will surpass the recommendations of the EIS in most locations. Standard attenuation track will be used for the parts of the alignment that are not close to sensitive receivers (such as near

[9] Modelling of Train Induced Vibration

Central Station and below the harbour); this is consistent with the EIS assumptions in these locations.

Sydney Metro's design also incorporates Floating Slab Track (FST) at stations that include Over Station Development (OSD). FST is an exceptionally high-performance track attenuation system that is not practical to install in the bored tunnels but is used at OSD stations to mitigate the risk of ground-borne noise and vibration propagating via the direct structural connection to future development above. A secondary effect of this FST treatment is that it will substantially reduce ground-borne noise and vibration at other receiver locations close to these stations.

I am satisfied that the track attenuation design is consistent with (and for the most part significantly better than) the recommendations in the EIS.

5.3 Predicted Outcomes

Residential Receivers

The predictions show that ground-borne noise levels will comply, by a small margin, with the RING design goals for residential receivers near the Marrickville and Chatswood dives, where the tunnels are shallowest. Predicted ground-borne noise levels are lower at locations further from the dives, where the tunnels are deeper, so they comply with the design goals by a greater margin. Predicted ground-borne vibration levels are significantly below the vibration velocity design goals (which are more stringent than those required by the guideline). This confirms that ground-borne noise is the controlling factor at residential receivers in this area, rather than vibration.

There are 3 residential receivers between Chatswood Dive and Crows Nest Station that required more detailed consideration during my review. One is a recently constructed apartment building in Crows Nest, with basements and foundations very close to the tunnels. The predictions indicated that the design goals could be exceeded, but vibration testing, using a rock breaker in the tunnel, confirmed that the predictions were conservative and that the revised estimates are within the goals. The other two receivers are apartment buildings in Artarmon. The predictions initially showed a marginal exceedance of the goals, but further investigation, including more detailed modelling with the MOTIV software, identified that the soil layer reflection effect had been overestimated at these locations. The revised predictions are within the goals.

Other Sensitive Receivers

The ground-borne noise and vibration predictions at the Royal North Shore Hospital show compliance with the applicable design goals at all affected buildings.

The predicted vibration level at the Medlab facility in Alexandria meets the VC-B criterion but exceeds VC-C. However, the predicted levels are lower than the ambient levels determined during vibration monitoring carried out prior to the tunnel boring process. On this basis, I consider that this outcome is acceptable.

The predicted noise level at Stage Door Productions in Alexandria is within the design goal of NR25.

5.4 Findings

I have reviewed the predicted ground-borne noise and vibration impacts and proposed track attenuation for the two sections of tunnel addressed in this letter. I consider that the predictions and proposed track attenuation measures are appropriate.

6 Conclusions

This letter completes my independent review, required by Condition D9 of the approval, of ground-borne noise and vibration design goals, predictions and track attenuation for the two sections of the Sydney Metro tunnels where track installation is scheduled to be completed first. These sections are:

1. Between the Chatswood Dive to the northern end of Crows Nest station, and
2. Between the southern end of Waterloo station to the Marrickville Dive.

I will submit one or more subsequent letters to address the other sections of the project, ensuring that they are submitted at least one month prior to the installation of track in those sections. I trust that this review provides the information you require, but please do not hesitate to contact me if you would like to discuss any aspect.

Yours sincerely

Dave Anderson

Director, Acoustic Studio Pty Ltd

Annex A:

Condition D9 of Sydney Metro Chatswood To Sydenham approval (SSI 15_7400)

Track Attenuation and Operational Ground-borne Noise Review

D9 The Proponent must nominate, for the Secretary's approval, a ground-borne noise specialist who is independent of the design and construction personnel, to review:

(a) the appropriateness of the proposed design (noise) objectives for ground-borne noise sensitive receivers; and
(b) predictions for operational ground-borne noise impacts, before the installation of track, in order to confirm the appropriate track attenuation required to meet the design (noise) objectives identified in (a).

The ground borne noise specialist must be submitted for the Secretary's approval before the review commences and the review must be submitted to the Secretary at least one month before the installation of track.

Annex B:

Approval of nominated Ground-borne Noise Specialist

NSW GOVERNMENT Planning & Environment

Contact: Jacqui McLeod
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Email: Jacqui.mcleod@planning.nsw.gov.au
Our ref: SSI 15_7400

Mr Fil Cerone
Principal Manager
City & Southwest Sustainability Environment & Planning
Sydney Metro, Transport for NSW
PO Box 588
North Ryde BC NSW 1670

Dear Mr Cerone

Sydney Metro City and Southwest – Chatswood to Sydenham (SSI 15_7400)
Condition D9 Ground-Borne Noise Specialist

Thank you for your correspondence of 25 August 2017 nominating Mr David Anderson from Acoustic Studio as the Ground-Borne Noise Specialist for the project.

The Department has reviewed Mr Anderson's curriculum vitae and is satisfied he has the appropriate qualifications and experience to undertake the role and functions of the Ground-Borne Noise Specialist, and is also suitability independent of the design and construction personnel.

Therefore, I approve the nomination of Mr David Anderson as the Ground-Borne Noise Specialist under condition D9.

If you have any queries, please contact Jacqui McLeod, Team Leader – Infrastructure Management on 02 9274 6454.

Yours sincerely

13/9/17

Stacy Warren
Director – Infrastructure Management
as delegate of the Secretary.

Department of Planning and Environment
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Annex C:

CV of approved Ground-borne Noise Specialist

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Dave Anderson

Acoustic Engineer
Director, Acoustic Studio

Career Overview

Dave joined **Acoustic Studio** Pty Ltd in 2014, from RailCorp NSW. He has over 25 years of experience in acoustics, noise and vibration across a wide range of fields and is a recognised expert in rail noise and vibration.

Dave graduated from the **Institute of Sound and Vibration Research** in the UK and joined **Arup Acoustics** in 1989. He moved to the Australian office of Arup Acoustics in 1995, and then joined the **Rail Infrastructure Corporation** (which later became RailCorp and Transport for NSW) as in-house noise specialist in 2002.

Dave has in-depth experience in noise and vibration issues associated with rail and tunnel projects and has co-authored numerous technical papers on the subject (a selection of relevant references is attached at the end of this CV).

Dave has extensive experience in communicating with a range of stakeholders, including community, project design teams, researchers, regulators, operations and maintenance personnel and senior executives.

Qualifications

Master of Engineering (MEng) in Acoustics and Vibration

Professional Associations

Member of the Australian Acoustical Society

Member of the Institute of Acoustics, UK

Member of the international committee for the **International Workshop on Railway Noise**

Chartered Engineer, UK

Expertise Areas

Dave's in-depth experience in noise and vibration includes prediction, impact assessment and design; the review, assurance and commissioning roles for numerous rail and tunnel projects; trouble-shooting and research & development for operational rail noise issues; and the role of Industry Chair for a Cooperative Research Centre project on rail noise.

In summary, Dave has in-depth experience in all areas of rail and tunnel acoustics, noise and vibration and across all stages of the asset life-cycle.

Key Projects

Melbourne Metro Rail Project (2016)

Peer review of project noise and vibration impact assessment carried out for the Environmental Effects Statement.

St Paul's Cathedral, Melbourne (2018 to present)

Peer review of noise and vibration impact management by Melbourne Metro contractor

Western Port Rail Freight Line, Victoria

Feasibility study, expert witness statement and presentation to panel hearing (2014). Client: Department of Economic Development, Jobs, Transport and Resources, Victoria.

Sydney Metro ('14 – present)

Sydney Metro is Australia's largest public transport infrastructure project.

Dave leads Acoustic Studio's roles as ***Technical Advisor*** and ***Acoustic Advisor*** for Sydney Metro for acoustics, noise and vibration.

Dave is also the **Independent Reviewer for Ground-borne Noise** appointed under the Planning Approval for the Chatswood to Sydenham project.

Dave's role spans the full life cycle of the project, including requirements specification, construction noise and vibration, engagement with planning authorities and regulators, design review and oversight, testing and measurement, and long-term strategic planning.

Western Sydney Freight Line (current)

Dave is project director of the team delivering noise and vibration technical advice for the Western Sydney Freight Line Stage 2 Project. This includes:

- Noise and vibration modelling and impact assessment;

- Co-design with Engineering and Land Use SMEs, Councils and the community;
- Stakeholder engagement and multi-criteria analysis;
- Novel noise control solutions

Inner West Light Rail (2016)

Dave led the test team investigating curve noise at Glebe. This involved measurement of rolling stock steering performance, noise and vibration, rail profile and rail friction.

Epping Chatswood Rail Link, Sydney ('02-'09)

Dave had extensive involvement in this project throughout the design, construction and commissioning stages, including:

- Peer review during design phase.
- Construction noise and vibration management during interface works at Chatswood and Epping.
- Noise and vibration design for track support system in Rail Enclosure Structure at Chatswood.
- Technical leader of noise task force during 2008, to resolve issues with in-train noise (culminating in the first use of rail dampers in Australia [3]).

Singapore Circle Line, Low Stiffness Rail Fastener (2016 and 2018)

In-tunnel and above-ground noise and vibration measurements to assess the effectiveness of replacement rail fasteners.

Sydney Airport Rail Link ('97-'99)

Noise and vibration prediction, assessment, design. Vibration mitigation design included the first significant use of under-ballast mats in Australia [2].

Other Relevant Experience

Sydney Light Rail, Sydney ('95-'97)

Dave provided expert advice to CityWest Development Corporation on noise and vibration impacts and mitigation requirements for residential and commercial redevelopments in Pyrmont, adjacent to the new light rail system.

Rail Clearways, Sydney ('05-'09)

Dave led the in-house technical review of noise and vibration impact assessments and mitigation designs for rail clearways projects, including Cronulla Duplication, Kingsgrove to Revesby Quad and South West Rail Link.

Wheel squeal research and development ('04-'13)

Dave has had a long-term involvement with wheel squeal issues, both in NSW and also in collaboration with rail agencies in South Australia and Queensland. The work spans:

- The first use of top-of-rail friction modifiers in Australia;
- The installation of a wayside angle-of-attack monitoring system on a curve (a world first) [4];
- Industry Chair of a Cooperative Research Centre (CRC) project on rail noise, including wheel squeal [6];
- Extensive track-based testing of lubrication and friction modifier treatments;
- Engagement with rail operators to investigate rolling stock curving performance.

Strategic Noise Action Plan, NSW ('12-'13)

Dave was seconded to the Freight and Regional Development Division of Transport for NSW to assist with the implementation of the Strategic Noise Action Plan (SNAP), which addresses noise from rail freight operations by tackling noise at source as well as ensuring appropriate controls are incorporated in the planning and the design of new projects.

Northern Sydney Freight Corridor, NSW ('11-'13)

Technical advice to support the development of the Operational Noise and Vibration Review.

Selected Technical References (copies available on request)

1. Dave Anderson, et al," 1dB per floor? How does noise and vibration propagate in high-rise buildings over railway lines", in Proceedings of the 13th International Workshop on Railway Noise, Belgium 2019
2. Anderson D, Harris M, *"New Southern Railway, Sydney – Noise and Vibration Attenuation Systems"*, Proc ExpoRail (Asia), Hong Kong, 2000
3. Coker D, Anderson D, *"Reducing In-train Noise on the Epping to Chatswood Rail Link"*, Proceedings of Conference on Rail Engineering 2010
4. Jiang J, Anderson D, Dowdell D, Wang C, *"The impact of angle of attack on curve squeal"*, Proceedings of World Congress on Railway Research (WCRR) 2013, Sydney, Australia
5. Anderson D and Hiller D, "Noise and vibration issues in tunnels", Tunnel Management International, 2000