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Freight rail noise in NSW: Comparisons of recent measurements against the Rail Noise Database

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ABSTRACT
The Transport for NSW Rail Noise Database (RNDB) has served as an invaluable source of reference data for railway noise assessments in NSW. However, for freight trains, the data is limited to tangent track only and arguably by its relatively small sample size. This paper presents a methodology to obtain passby data from a single channel microphone located close to track, with linkages to databases containing relevant operational details including speed and train consists. The paper also presents a comparison of the RNDB against selected measurement campaigns undertaken since the last revision of the RNDB, offers some insights into curve gain in NSW and observations pertinent to refining currently adopted noise modelling methods.

1 INTRODUCTION

The Rail Noise Database (RNDB) is a collection of rail noise measurements undertaken in NSW with the aim of establishing a consistent set of data for rail noise modelling and assessments. The RNDB is currently maintained by the Asset Standards Authority arm of Transport for NSW. Stage 1 of the database was published in 1996, followed by Stage 2 in 2000. The current iteration of the database ('Stage 3') was published in 2015. Stages 1 and 2 of the database primarily focused on passenger train classes. In terms of freight rail, Stage 1 of the database included 53 wagon consists and 61 locomotives while stage 2 of the database included 95 consists and locomotives. The current iteration of the database includes 282 consists and between 50 and 83 locomotives on various grades, which while significantly larger than previous iterations is still limited in sample size. The current iteration of the database is also limited to tangent track measurements only and does not provide any guidance on curve gain (the additional noise generated by trains travelling through tight radius curves) or other aspects of freight rail noise. This is despite the inherent (and significant) variability in freight noise levels (compared to passenger rail noise) and the prevalence of mixed rail corridors and tight curves in NSW. Basutu et al. (2015) noted that approximately two-thirds of all freight rail noise related complaints received by Transport for NSW relate to curve noise from freight trains.

The limited size (and scope) of the freight noise dataset leads to some uncertainty in whether the adopted source noise levels are 'conservative' for the assessment of future rail noise impacts. Schulten et al. (2015) note that *"source levels…should be towards the upper end of possible noise level range to capture a 'worst case' assessment"*. For example, NSW (and other states) generally rely on the curve squeal corrections outlined in Schall-03 – i.e. a 3 dB curve gain correction to rolling noise for curve radii less than 500 m and a 8 dB curve gain correction to rolling noise for curve radii less than 300 m. Schulten et al. (2015) note that *"whilst the current version of the database (Stage III) is relatively small, it is intended for the database to be continually updated with additional measurement data to support the improved accuracy of noise modelling and implementation of cost effective mitigation measures"*. In the years since the publication of Stage 3 of the RNDB, extensive measurement campaigns of passenger and freight noise have been undertaken in NSW, including unattended measurements on many of the curve noise hotspots on the network. These measurements were undertaken using a single channel microphone, typically located within the rail corridor. The challenge for these measurements (or for any other typical rail noise measurements) is to obtain concurrent speed and consist data – therefore, making the data suitable for the derivation of source noise levels and potential inclusion into reference databases such as the RNDB. This paper provides a framework for bridging this data gap without any additional equipment requirements and provides a comparison of approximately 3,000 freight train passbys from 11 sites on the NSW network with the data contained in the RNDB.

2 OBJECTIVES

The objectives of this paper are as follows:

- To present an analysis methodology that relies on an unattended single channel microphone for obtaining data suitable for inclusion into the RNDB (i.e. rail passby noise data, speed and train consists). The aim of this methodology is to eliminate the requirement for attended measurements or axle counters to obtain rail operational data. The shortcomings of this approach are also discussed.

- To apply the above methodology to a number of measurement campaigns undertaken since the release of Stage 3 of the RNDB. The focus is primarily on curved track. However, a number of tangent track sites are also included. The results are compared against the RNDB.
- To outline a methodology to calculate curve gain without simultaneous tangent track measurements.
- To provide some insight into the nature and percentage of freight noise sources such as impact noise, flanging and squeal at the selected measurement locations.
- To provide some recommendations for source noise levels and noise corrections for future rail noise assessments. It should be noted that the aim of this work is to feed into a large scale model validation exercise in NSW, to be published at a later date.

3 METHODOLOGY

The data gathering methodology was consistent across all monitoring locations. It included measuring acoustic parameters relevant to rail noise using a single channel microphone (including the L_{Aeq} and L_{AFmax} descriptors) in 100 millisecond intervals. Audio files (in the .wav file format, sampled at 48000 Hz and 24 bits) were also recorded at specific threshold levels. The threshold levels were site specific and dependent on the distance of the microphone from the track as well as the ambient noise characteristics of the area. The measurements were recorded at distances ranging from 7 to 28 m from near track (up to 32 m from far track). Measurements were free field at nine of the eleven sites. At two locations, some minor reflections from a fence are possible though not considered to be significant. The locations, including line, number of tracks, distances, microphone height, average speeds (refer to Section 3.1.2), curve radius and track gradients are summarised in Table 1.

Table 1: Monitoring locations selected for analysis

Site ID	Line	Gradient	Curve radius	Distance - near track centre to microphone	Estimated microphone height above top of rail	Number of tracks	Average speed (km/h)
A01	Illawarra	1 in 196	Straight	19 m	2 m	2	57
A02	Main North	1 in 416	550 m	8 m	1.2 m	2	60
A03	Main North	1 in 109	300 m	16 m	1.5 m	2	52
A04	Main South	1 in 100	Straight	13.5 m	2 m	3	60
A05	Main North	1 in 66	440 m	7.5 m	1.2 m	2	54
A06	Main South	1 in 200	Straight	7 m	1.1 m	3	72
A07	Main West	Level	260 m	22 m	1.2 m	2	40
A08	Main South	1 in 100	Straight	12.5 m	1.5 m	3	61
A09	Main North	1 in 75	480 m	14.5 m	2 m	2	62
A10	Illawarra	1 in 235	240 m	28 m	1.5 m	2	48
A11	Illawarra	1 in 150	310 m	19 m	1 m	2	54

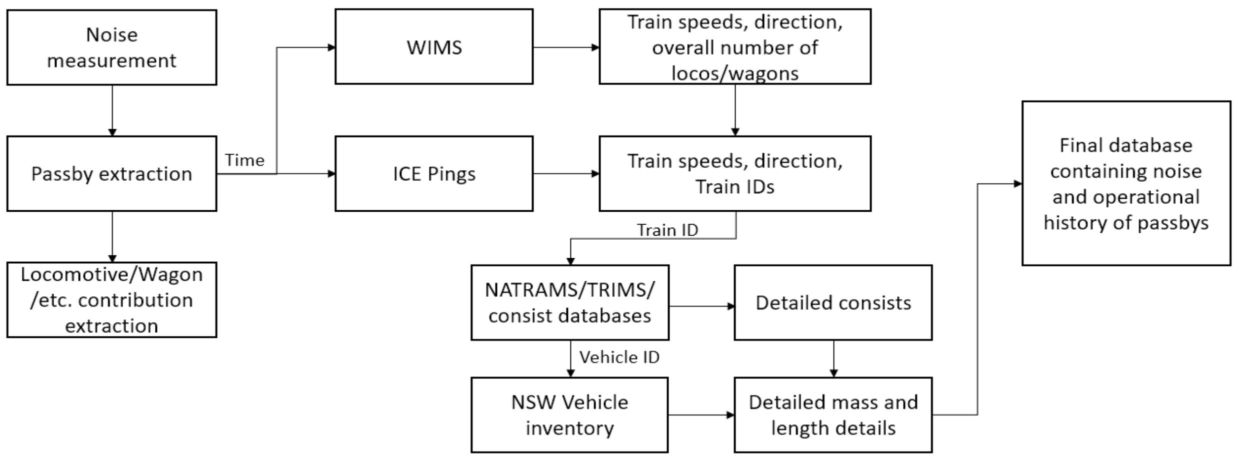
3.1.1 Passby extraction

The data from each location was initially analysed using a script developed in Matlab. Train passbys were extracted based on a time-above-level algorithm. The trigger parameters were customised for each location individually with the acoustic events segmented to the duration where the noise levels decreased 5 dB below the cutoff threshold. Freight events were classified as events over 30 seconds in duration. Passby times and durations were used to 'clip' the relevant passby audio from the broader ambient audio data. The time history for each freight passby was further extracted and manually examined by listening to the audio to exclude extraneous events and separate locomotive and wagon noise. In addition, where feasible, wagon noise sources were further sub-categorised manually into "good wagons", corresponding to wagon passby periods without significant peaks (as per the methodology adopted in the RNDB). This manual classification was refined by excluding 'good' wagon segments where the standard deviation of the segment was greater than 3 dB or the total duration of good wagon segments was less than ten seconds. These choices, while admittedly arbitrary, were selected to provide a mathematical framework to the initial manual segmentation process. Other noise sources, such as horn noise, squeal, flanging and impact noise were also identified and tabulated by listening to passby audio.

3.1.2 Operational data

Concurrent to the process of extracting rail passby events, the passby time was correlated with locomotive In-Cab Communications Equipment (ICE) ‘ping’ data and Wayside Information Management System (WIMS) data (where available). The WIMS system is operated by Sydney Trains and collates data from their condition monitoring stations distributed across the network. The ICE data, in contrast, is broadcast by each train at regular intervals (~1 minute) as it traverses the network. The WIMS data is useful for obtaining the overall number of locomotives, wagons, leading locomotive, train direction and speed, but it is limited by the number of WIMS sites and the lack of detailed consist data. The WIMS data was used to validate the ICE data where a WIMS site was located close to the noise monitoring location.

The ICE ping data was extracted for each area of interest around the monitoring location. The pings contain GPS location, locomotive, train ID, direction and speed. The ICE data was used to calculate both an average and maximum speed for each passby (if the train had more than one ICE ping) The train IDs from the ICE data were used to extract detailed consist histories, including individual locomotive and wagon classes, from the train consist databases. Finally, the vehicle IDs were compared to NSW vehicle inventories to obtain train length and loading details. The train speeds are required to normalise all passbys to a fixed speed (i.e. 80 kph) while the consist history enables the identification of noisy locomotive or wagon classes. The entire process is shown schematically in Figure 1.



Note: NATRAMS refers to ARTC’s National Rail Access Management System while TRIMS refers to the Transport for NSW Train Running Information Management System.

Figure 1: Methodology to obtain rail passby and operational details

4 WAGON NOISE

4.1 Noise levels and comparison with the RNDB

The measured noise levels, normalised to reference conditions, are summarised in Table 2 and compared with the RNDB. This includes correcting the measured noise levels to a reference height of 1.5 m above Top of Rail (TOR), 15 m from the track centreline and a speed of 80 km/h. These corrections are as per the RNDB:

- Speed correction: $+N*\log_{10}$(reference speed/speed), where N = 30 and reference speed = 80 km/h. For a significant number of wagons (‘all’ wagons), the speed correction does not closely follow a 30 log correction due to the influence of factors other than wheel/rail rolling noise. For all locations, results without a speed correction are also provided in brackets. The 30 log correction is reasonable for rolling noise from ‘good’ wagons.
- Distance correction: $+N*\log_{10}$(distance/reference distance), where N = 10 (L_{Aeq}), N = 13.5 (L_{Amax}) and reference distance = 15 m.
- Microphone height correction: $+N*\log_{10}$(reference height/height), where N = 3 and reference height = 1.5 m.

For each site, the percentage of wagon passbys exhibiting squeal, flanging or impact noise has also been identified, noting that these categories are non-exclusive. For example, a passby exhibiting flanging, squeal and impact noise would be included in each category. The RNDB measurements are plotted against the dataset (all track and tangent track, separately) in Figure 2, highlighting that the RNDB data (bold black) typically forms a sub-set of the larger dataset. However, the tangent track comparison shows that there are a few outlier events in the

RNDB due to squeal. The speed corrected L_{Aeq} levels for the combined curve and tangent track dataset show good agreement with the RNDB, with the overall levels for both 'all' and 'good' wagons lying within 1 dB of the RNDB values. This comparison is considered to be reasonable as a number of events in the RNDB also contain squeal, including events at low speeds with squeal (i.e. large speed corrections), which skew the overall values. The maximum noise levels show considerably greater variance (even excluding the sites with curving noise), with the 95th percentile L_{AFmax} levels for the current dataset (good wagons only) calculated to be 7 dB higher than the RNDB.

Table 2: Summary of measured wagon noise levels and comparison against the RNDB

Site ID	# Train passbys	Percentage with squeal, flanging or impact, %			# Good wagon passbys	Energy average $L_{Aeq,Tp}$		Average $L_{Aeq,Tp}$		L_{AFmax}, 95th percentile	
		w/ sq	w/ fl	w/ imp		All	Good only	All	Good only	All	Good only
A01 (Straight)	66	8%	5%	2%	41	81 (76)	78	79 (74)	77	101 (93)	88
A02 (550 m)	442	67%	41%	3%	53	91 (87)	82	88 (84)	81	109 (105)	88
A03 (300 m)	306	31%	81%	64%	0	90 (83)	-	87 (81)	-	109 (102)	-
A04 (Straight)	371	0%	0%	2%	278	86 (81)	85	83 (79)	83	97 (92)	96
A05 (440 m)	378	19%	65%	19%	128	90 (83)	85	87 (82)	84	108 (103)	93
A06 (Straight)	269	2%	6%	31%	171	83 (80)	80	80 (78)	79	95 (92)	87
A07 (260 m)	151	38%	52%	9%	45	87 (78)	82	85 (76)	82	107 (98)	89
A08 (Straight)	360	0%	0%	0%	260	85 (80)	84	82 (78)	82	97 (92)	95
A09 (480 m)	308	67%	0%	0%	84	88 (84)	82	86 (83)	82	106 (102)	94
A10 (240 m)	101	67%	89%	18%	17	96 (89)	87	91 (84)	82	117 (110)	97
A11 (310 m)	107	60%	0%	0%	31	94 (89)	89	91 (85)	87	115 (109)	100
Overall (all sites)	**2859**	**-**	**-**	**-**	**1108**	**89 (84)**	**84**	**85 (81)**	**82**	**108 (102)**	**95**
Overall (tangent track only)	**1066**	**-**	**-**	**-**	**750**	**84 (80)**	**84**	**82 (79)**	**81**	**97 (92)**	**95**
RNDB Site 4	104	-	-	-	14	88	76	85	75	101	Not calculated due to low # of passbys
RNDB Site 5	49	-	-	-	13	86	86	85	86	98	
RNDB Site 6	44	-	-	-	4	93	83	89	82	102	
RNDB Site 7	46	-	-	-	7	93	83	86	83	107	
RNDB Site 8	39	-	-	-	5	86	79	81	79	100	
Overall RNDB (all sites)	**282**	**-**	**-**	**-**	**43**	**90**	**83**	**85**	**81**	**103**	**88**

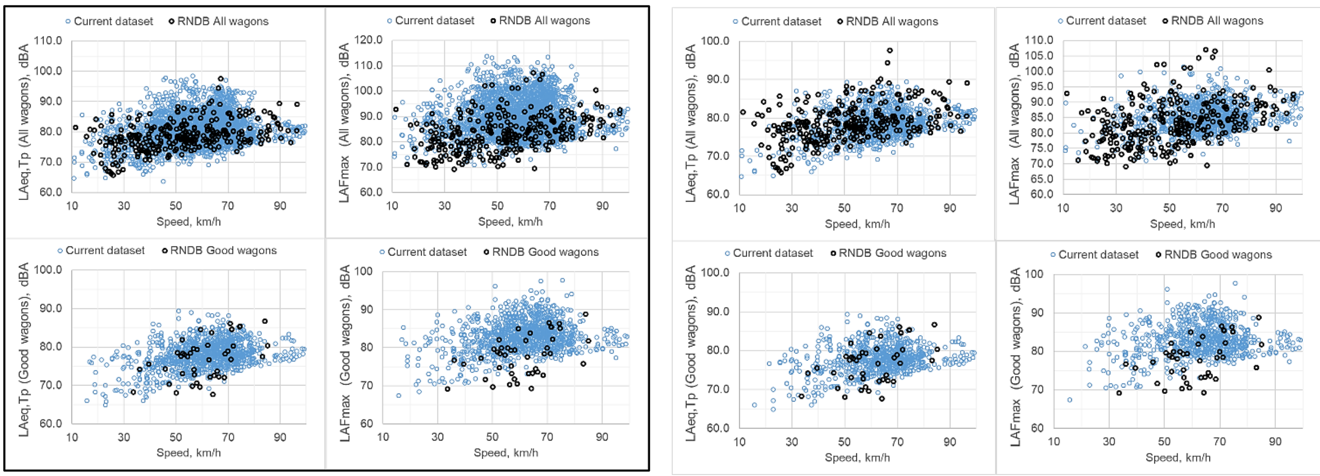


Figure 2: Comparison of current dataset vs. RNDB – all tracks (left, border) and tangent track only (right)

4.2 Curve gain

The RNDB report notes that "*Consistent with the recommendations made in the TfNSW report, additional measurements are recommended to further understand the curve gain values that should be adopted in noise modelling algorithms. It is recommended that additional measurements to quantify curve gain at various sites include an assesment of rail profile at each site, as this was shown to have an affect on the curve gain for the original study.*" The work undertaken by Basutu et al. (2015) provided curve gain values at a few sites. However, they used equivalent tangent track data to derive a gain for the same passby when travelling around the curve. As no measured tangent track data could be assigned to each passby in the current exercise, alternative methodologies have been evaluated to assess curve gain.

- Method 1: Difference in the average (or 95th percentile) overall values of all wagons (at 15m) and the average (or 95th percentile) overall value of 'good' wagons (at 15m, as defined in Section 3.1.1). No speed corrections are applied to avoid over-correcting squealing wagons for speed. This approach has the potential to over-estimate the curve gain if good wagons are skewed towards quieter wagons.
- Method 2: Difference in the average (or 95th percentile) overall values of all wagons and all wagons without squeal or flanging noise. At one site, the number of passbys without squeal or flanging is too low to meaningfully derive this correction. All levels are again compared without any speed corrections.

Results at all sites, including tangent track, are shown in Table 3. The tangent track sites are used as a control to test the validity of the adopted methods. It is acknowledged that these results do not take into account the variances in track roughness resulting from corrugation (a common feature in tight curves). However, the effects of roughness are not anticipated to significantly change the overall 'all' wagon noise levels (which would be dominated by squeal events). To the extent that roughness would influence the noise from 'good' wagons, the calculated curve gains are expected to be conservative. The results indicate that the curve gains calculated using the two methods are in general agreement. The derived curve gains agree with the findings of Basutu et al. (2015) that *"relying on standard corrections to model curve noise levels introduces the potential that impacts will be under or overestimated"*. Notably, the Schall-03 transition to a lower curve gain at a radius of 300 m is not supported, with up to 7 dB gains calculated for a 550 m curve.

The derived curve gains are plotted against curve radius and occurrence of squeal in Figure 3. The results suggest that, insofar that squeal can be considered as a probabilistic process, the gain is dependent on the percentage of passbys exhibiting squeal rather than curve radius (i.e. an increased number of squealing passbys increases the likelihood of a passby exhibiting severe squeal). Perhaps counter-intuitively, increasing curve radius does not decrease the percentage of passbys exhibiting squeal (in either frequency or magnitude). This lack of sensitivity to curve radius may be partially due to the tendency to squeal being dependent on wagon design features (and the resulting bogie warp), as discussed elsewhere e.g. Jiang et al. (2015) and Hanson (2021).

Table 3: Calculated curve gain at monitoring sites

Site ID	Gradient	Curve radius	% w/ squeal	Method 1: $L_{Aeq,Tp}$	Passbys without sq or fl	Method 2: $L_{Aeq,Tp}$	Method 1: L_{AFmax}, 95th percentile	Method 2: L_{AFmax}, 95th percentile
A01	1 in 196	Straight	8%	1	59	0	11	4
A02	1 in 416	550 m	67%	7	34	5	20	12
A03	1 in 109	300 m	31%	-	30	5	-	12
A04	1 in 100	Straight	0%	1	371	0	1	0
A05	1 in 66	440 m	19%	2	85	1	15	12
A06	1 in 200	Straight	2%	1	249	0	8	0
A07	Level	260 m	38%	1	34	3	15	8
A08	1 in 100	Straight	0%	1	360	0	3	0
A09	1 in 75	480 m	67%	4	101	3	11	9
A10	1 in 235	240 m	67%	9	3	-	28	-
A11	1 in 150	310 m	60%	5	43	4	17	16

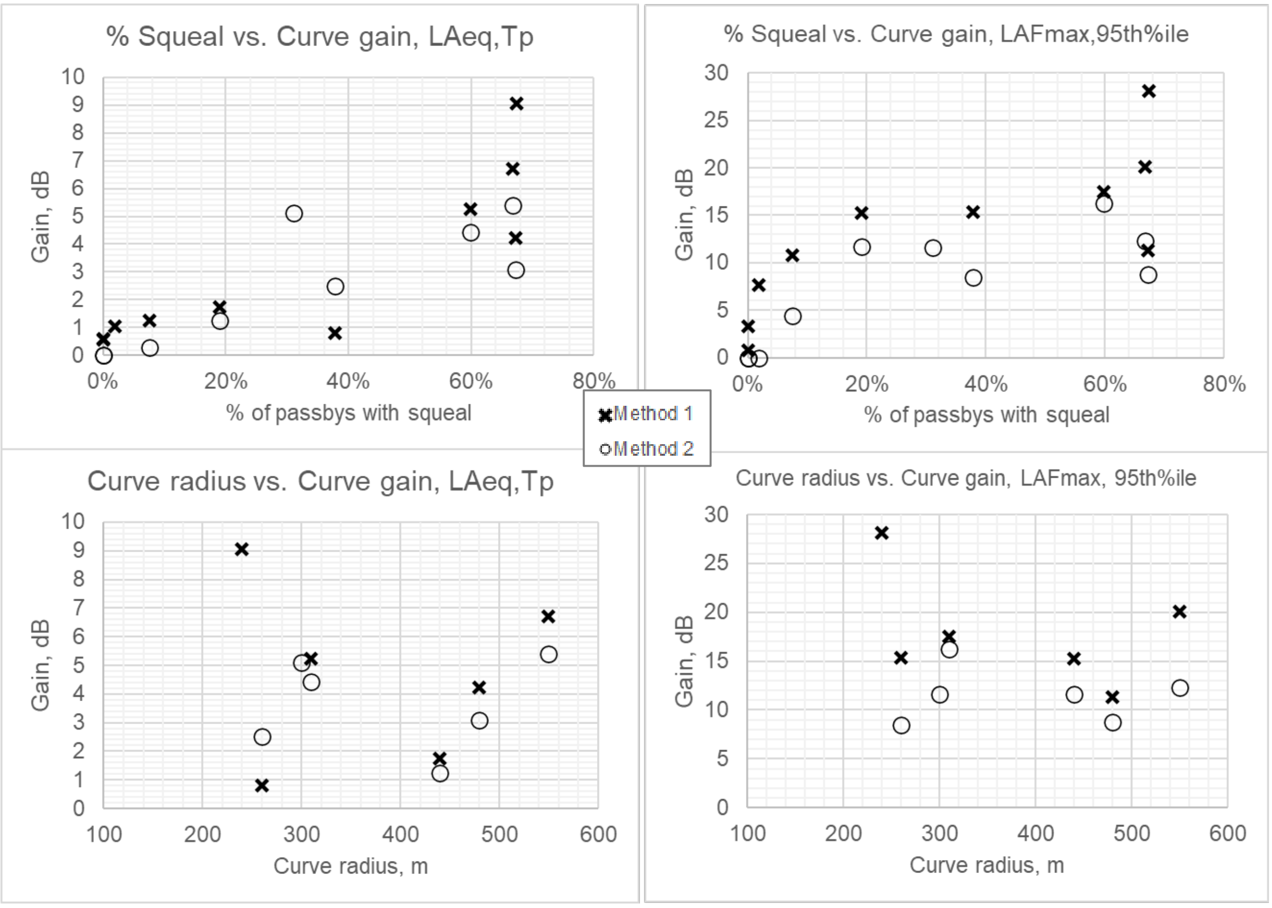


Figure 3: Curve gain plotted against % passbys with squeal and against curve radius

5 ENGINE NOISE

5.1 Noise levels and comparison with the RNDB

The measured locomotive noise levels, normalised to reference conditions, are summarised in Table 4 and compared with the RNDB. All corrections were as per wagon noise except the lack of a speed correction as engine noise is expected to be independent of speed (rather, it is related to gradient/notch). The locomotive class distribution across the dataset is shown in Figure 4, with mixed consists being the dominant locomotive class. Table 4 also provides commentary on whether the notch behaviour is expected to be flat, downhill or uphill. However, more work is required to confirm this behaviour and further distinguish notch settings at these locations. One site has been excluded based on squeal peaks forming part of the locomotive noise source. The overall results are, again, in good agreement with the RNDB for energy averaged levels. Maximum noise levels show greater deviation, with measured uphill and flat grade maximum levels 5 dB higher than the RNDB values and downhill levels 2 dB higher than the RNDB values. In undertaking this comparison, we note that the RNDB did not include mixed locomotive consists. However, while a separation between mixed and non-mixed consists is not provided in Table 4, the removal of mixed consists does not significantly change the analysis and both the overall maximum and energy averaged levels remain essentially unchanged from the values presented in Table 4. Results at individual locations differ significantly even for seemingly equivalent grades. This may be due to either the mix of locomotive classes operating at that location or locomotive notch settings. Additional work is required to further understand this.

Table 4: Summary of measured locomotive noise levels and comparison against the RNDB

Site ID	# Locomotive passbys	Track	Curve	Gradient	Energy average $L_{Aeq,Tp}$	Average $L_{Aeq,Tp}$	$L_{AFmax, 95th percentile}$	Expected Grade[1]
A01	34	Dn	Straight	196	82	80	91	Flat
A01	35	Up	Straight	196	86	84	95	Flat
A02	218	Up	550	416	88	87	96	Downhill
A02	226	Dn	550	416	89	88	99	Uphill
A03	156	Up	300	109	87	85	96	Downhill
A03	151	Dn	300	109	88	85	98	Uphill
A04	230	Bi	Straight	100	86	84	98	Flat
A04	74	Dn	Straight	100	88	87	98	Flat
A04	73	Up	Straight	100	84	83	94	Flat
A05	187	Dn	440	66	85	84	94	Downhill
A05	191	Up	440	66	91	90	101	Uphill
A06	212	Bi	Straight	200	86	84	97	Flat
A06	31	Dn	Straight	200	87	84	95	Flat
A06	27	Up	Straight	200	81	79	89	Flat
A07	88	Dn	260	Level	88	87	97	Uphill
A07	64	Up	260	Level	86	83	95	Flat
A08	77	Dn	Straight	100	88	86	96	Flat
A08	71	Up	Straight	100	85	84	93	Flat
A08	230	Bi	Straight	100	86	84	96	Flat
A09	154	Up	480	75	90	89	99	Uphill
A09	155	Dn	480	75	89	87	98	Downhill
A10	46	Dn	240	235	88	87	100	Flat
A10	55	Up	240	235	88	86	101	Flat
A11	55	Dn	310	150	88	87	96	Flat
A11	53	Up	310	150	93	91	101	Flat, affected by squeal
Overall (all sites)	**2893**	**-**	**-**	**-**	**88**	**93**	**98**	
Overall (Uphill)	**810**				**90**	**88**	**99**	
Overall (Down-hill)	**716**				**87**	**86**	**96**	
Overall (Flat)	**1314**				**86**	**84**	**97**	
RNDB (Uphill)	**80**	**-**	**-**	**-**	**89**	**88**	**94**	
RNDB (Down-hill)	**83**	**-**	**-**	**-**	**87**	**84**	**94**	
RNDB (Flat)	**50**	**-**	**-**	**-**	**88**	**86**	**92**	

Note 1: To be confirmed based on further review of sites and data.

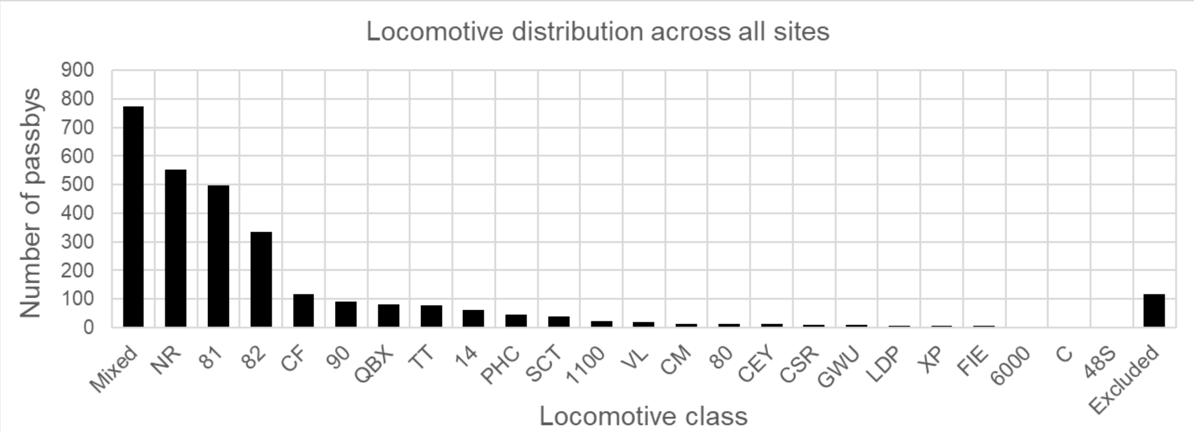


Figure 4: Locomotive class distribution

6 SHORTCOMINGS

At least two other factors are known to affect noise emissions from freight rail – the track decay rate and the rail/wheel roughness. It is acknowledged that no measurements of these two variables were undertaken as part of these measurement campaigns. However, the track decay rate is expected to be relatively consistent across the network as all sites had the same track form and the effect of deviances in decay rate (in the absence of dampers, etc.) is expected to be minor.

Roughness may have a greater impact- particularly on 'good' wagons on tight curves with corrugation. Indications of comparative rail roughness can be obtained by tracking the same train through groups of locations where the measurement was undertaken during the same time period (as was the case for a number of a curves examined in this paper). However, this has not been undertaken at this stage and we note that the RNDB also does not include roughness measurements at any of the freight measurement locations. The RNDB even notes that two of the sites *"appear to be influenced by elevated rail roughness levels"*. Therefore, the comparison against the RNDB is considered to be valid even without the measurement or derivation of rail roughness.

7 IMPLICATIONS FOR NOISE MODELLING

The larger dataset confirms the highly variable nature of noise from operating rail systems. Source level assumptions from the RNDB have the potential to be non-conservative for noise assessments and site specific measurements should be undertaken where feasible. Adjustments to maximum noise levels in the RNDB may also be warranted based on the analysis presented in this paper. Similarly, currently adopted curve gain values may be non-conservative, with a transition at 300 m curve radius not supported by the data. Other aspects of squeal and impact noise, including adopted corrections, may also need to be further investigated.

8 CONCLUSIONS

A methodology to match operational rail data with passby noise data has been outlined. This has unlocked tremendous potential in terms of analysing noise against specific locomotive and wagon types, train lengths and loads, train speeds and hence normalising data for updates to standardised source levels such as are presented in the RNDB. The methodology has been used to examine freight rail noise at various locations on the NSW network. The results indicate that maximum noise levels in the RNDB need to be adjusted upwards to properly represent freight train noise impacts. Furthermore, curve gain may be less strongly tied to curve radius than previously thought, and assumptions relating to curve radius and noise could be non-conservative.
It is hoped that the approach outlined above leads to the validation of modern rail noise algorithms and a better understanding of curve gain.

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