Maintenance effects on rolling noise – metro and light rail

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ABSTRACT

The combined roughness of the wheel/rail interface is an important factor in railway rolling noise emissions. Although it is widely acknowledged that track condition influences noise levels, the potential changes over time due to wear and maintenance cycles are rarely addressed in impact assessments for proposed new systems in NSW. Instead, it is commonly assumed that track will be maintained in good condition with noise emissions that are stable. This assumption may be disconnected from the reality of light rail and metro transit maintenance practices. A series of case studies and measured data is provided to illustrate the range of different rail roughness conditions and corresponding noise levels that can be observed over time on real-world operating systems. On some systems, there is relatively little variation in rail roughness over time and train noise emissions are very similar at comparable locations. Others can see see dramatic increases in noise soon after rail grinding. A case study is provided where measurements at different tangent track locations on the same network with the same rolling stock indicate a difference of 26 dBA in passby noise levels, attributable to rail condition and maintenance state.

1 INTRODUCTION

It is well established that the combined roughness of the wheel/rail interface is an important factor in railway rolling noise emissions (Thompson, 2009). If rolling stock is not tread-braked then wheel roughness tends to be relatively low (Dings and Dittrich, 1996), in this case rail roughness and track condition can have a considerable influence on rolling noise emissions. Metro and light rail systems commonly utilise disc brakes so on these systems rail roughness often dominates over wheel roughness.

Different types of rail systems have different features and operational characterics. Grassie (2012) identifies differences in the influence of rail roughness on noise between different system types: heavy haul, high speed and mixed freight/passenger systems typically display relatively low levels of rail roughness; metro systems are distinguished by a tendency to corrugate (especially on curves) and by higher levels of short wavelength roughness; while light rail systems have relatively high levels of broadband roughness which may result from sanding to improve adhesion. Grassie notes that one factor in the increased tendency of metro track to corrugate is the tightly controlled operational speeds on these systems, relative to mixed traffic lines. Another factor in higher roughness and corrugation on metro and light rail networks may be simply that these systems tend to incorporate more small-radius curves than higher speed or heavy rail lines.

Sydney Metro North West commenced operation in 2019 as Australia's first fully-automated rail network. The CBD and South East Light Rail also commenced operation in late 2019, and Parramatta Light Rail is under construction. Transport for New South Wales (TfNSW) have identified a $72.2 billion investment in transport projects over the next four years, including expansion of the automated driverless metro network and light rail (TfNSW, 2020). This represents a shift in the urban passenger rail network in NSW to metro and light rail from predominantly heavy rail systems, which in many cases operate on shared infrastructure with freight traffic. This paper discusses the potential implications of this shift in terms of rail noise emissions, referencing the challenges experienced on similar systems elsewhere in maintaining low noise / low roughness track condition.

Although it is widely acknowledged that rail roughness and track condition influences rolling noise levels, the potential for variation in track condition is rarely addressed in noise impact assessments or the design of proposed new metro and light rail transit systems in NSW. Instead, noise impact assessments commonly assume that track will simply be maintained in good condition (i.e., rail grinding whenever required to control roughness and noise), and hence noise will be stable and consistent over time. This assumption has proved to be reasonable for assessment of historical heavy passenger rail projects in NSW, but may not reflect the reality of maintenance challenges on operating metro and light rail systems. In particular, these systems increasingly aim to reduce headways, increase train numbers, and maximize operating hours, these factors have the combined effect of increasing traffic and hence wear, while minimising available time for maintenance such as rail grinding.

Activities such as rail grinding occur periodically at intervals that can be months or years apart, depending on system requirements. Grinding intervals are carefully planned to achieve maintenance objectives that are rarely solely driven by noise. If transit systems rely on network-wide contract grinding campaigns, maintenance scheduling can depend more on availability of equipment than the need for noise mitigation at a specific problematic location. It may not always be possible to grind a track section immediately when a noise issue becomes apparent.

This paper summarises previous published studies relating to noise, rail condition and maintenance practices on light rail and metro systems internationally. An additional case study is presented of the first fully-automated driverless rail network in the world, the Vancouver Skytrain in Canada which commenced operations in 1986. Recent measurements on the Vancouver system including an extension that opened in 2016 are provided as an example of the potential for variation in noise with changing track conditions and maintenance cycles on a high-frequency automated transit system.

2 REFERENCE SOURCE NOISE LEVELS FOR RAIL TRANSIT PROJECT NOISE PREDICTION

In the environmental impact assessment stage of proposed rail transit projects a common approach is to rely on reference source emission levels for noise predictions. These reference levels typically assume track in good condition. In NSW the rolling stock source reference data in the NSW Rail Noise Database (TfNSW 2015a, 2015b) for electric passenger and light rail rolling stock were all measured under track conditions (roughness and decay rate) similar to that defined in ISO 3095:2013. For all these train types, the Rail Noise Database states “on the basis of the measured track roughness levels, the source noise levels are likely to be controlled by the rolling stock, rather than the track condition.” Therefore the reference noise levels generally represent the realistic best case noise emissions for a particular track and rolling stock type. Track condition correction factors are not typically added to noise predictions.

The NSW Rail Noise Database (TfNSW, 2015b) includes some limited data for Sydney light rail with measurements of Variotram and Urbos 3 rolling stock operating at around 40 km/h on the Inner West Light Rail Extension on ballasted track (this line has been converted to light rail from former freight operations). Rail roughness was measured to be close to ISO 3095:2013 limits. No data is currently available in the database for Citadis rolling stock on the CBD and South East network, or for Metropolis rolling stock operating on Sydney Metro North West. Noise predictions for the first extension to the metro network assumed that noise levels will be similar to or less than existing double-deck rolling stock operating on the Sydney heavy rail network (SLR, 2017).

In North America rail transit impact assessments normally reference US Federal Transit Administration (FTA) guidance (FTA, 2018) for reference source noise levels. These source levels are described as being “typical of systems designed according to current engineering practice”. No adjustments are applied to predictions of airborne noise due to track condition or corrugation (although a 10 dB adjustment is recommended for assessment of vibration and ground-borne noise in situations with corrugated or worn track). The US FTA guideline indicates that rail grinding approximately every two years is expected to minimize noise problems related to corrugation in most cases.

3 LITERATURE ON VARIABILITY IN RAIL CONDITION

3.1 NSW studies

Several studies have examined noise variability and more specifically changes in rail acoustic roughness on the Sydney system. Lawrence (2004) describes ground-borne noise increases above a City Circle tunnel due to corrugation formation, the track in question is curved with minimum radius of 207 m. Grinding resulted in 10-15 dB reductions in noise levels in the dominant frequency bands. Vegh et al (2014) report rail roughness measurements taken on tangent track and a large (860m) radius curve on the Epping to Chatswood Rail Line (ECRL), five years apart following acoustic rail grinding. These results showed that rail condition improved rather than worsened over time. Also included in this paper are rail roughness measurements of four other locations on the Sydney network, reproduced in Figure 1 with an example result from the ECRL measurements. These results show corrugation on curves in the city underground tunnels, rails in relatively good smooth acoustic condition on the Main North Line (mixed freight and passenger traffic) around two years after grinding, an example from the Cronulla line where grinding resulted in relatively high rail roughness and the ISO 3095:2013 reference spectrum.

Some Sydney rail lines do show the tendency for corrugation on the low rail of small radius curves that are common on dedicated passenger rail transit systems worldwide. However in other areas, particularly on mixed freight and passenger lines, available data indicates rail acoustic condition does tend to be reasonably stable. Roughness has been observed to improve rather than deteriorating in the period following rail grinding, including examples of rails that maintain very good acoustic condition over long periods of time such as the ECRL and Main

North examples in Figure 1. Standard grinding required as part of normal regular maintenance can sometimes result in increased rail roughness and hence noise.

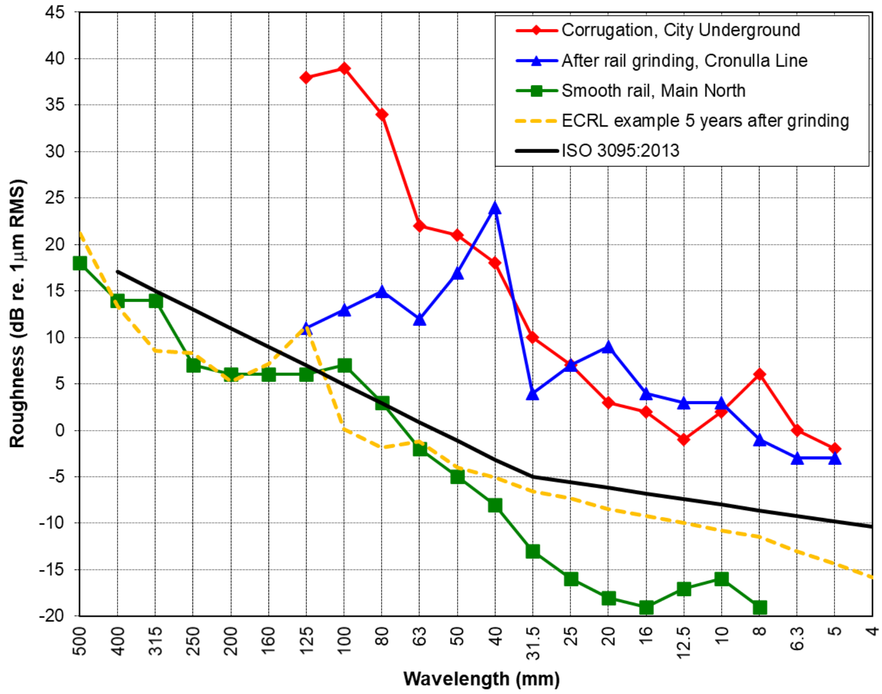

Figure 1: Range of rail roughness measured around Sydney network, adapted from Vegh et al., 2014.

3.2 International metro examples

Grassie (2012) observes that metro systems are particularly prone to corrugation, based on measured rail roughness data from both rails on four lines in four different countries. The tendency for the low rail to corrugate on curves is described as resulting in a 30 dB difference in roughness between high and low rails across much of the wavelength range of interest. The observed trends in roughness were “remarkably consistent” across the different metro systems. Additional examples of severe rail roughness, corrugation and high noise on metro systems are reported on metro systems in China by Liu et al. (2021), linked to high traffic loads and proportion of curved track, the curve radius of the majority of track being in the range of 300-500 m. They report noise levels in car almost 20 dB above the applicable goals, due to roughness and corrugation. On one route, 88% of the track exceeds the operational noise criterion.

3.3 Track condition on light rail systems

In relation to light rail systems, Grassie (2012) states that”

> *“irregularities are not only significantly higher than the ISO 3095 limit throughout the wavelength range but also greater than irregularities on other types of railway system except for the heavily corrugated low rail on a metro”*

Chiacchiari et al. (2016) also report broadband high rail roughness levels measured at multiple locations on an Italian tramway with embedded track, with roughness levels ranging from around 5 to 20 dB higher than ISO 3095:2013 roughness limits. Chiello et al., (2019) report rail roughness from a French tram network, on tangent and curved track sections with various different rail types (grooved and vignole) and surfacings (embedded, slab and ballasted). They observed rail roughness levels much higher than those proposed for conventional rail systems in the CNOSSOS-EU noise prediction method (Kephaloplous et al., 2012), in some cases by 10-15 dB.

Byrne (2017, 2018) measured rail roughness and noise before and after rail grinding on the Dublin light rail system. An overall noise reduction following grinding of 12 dBA was observed on a slab track section (not embedded) with Citadis rolling stock and speeds around 60 km/h. Less substantial reductions around 5 dBA were observed in embedded track sections with operating speeds around 30 km/h, this is still a noticeable difference particularly considering rolling noise is reduced at lower speeds. Corrugation was a factor in rolling noise emissions.

4 CASE STUDY VANCOUVER SKYTRAIN VARIATION IN ROLLING NOISE

The SkyTrain system commenced operations in 1986 with several expansions since. The system today is comprised of roughly 60 km of standard gauge double track fully automated guideway, with 39 stations, running up to 21 hours per day, seven days a week. Most of the system is built on elevated guideway; however, there are sections of tunnel and at-grade track. All track is slab track with 115RE rails supported by resilient baseplate-type direct-fix fasteners, either the original Lord baseplate or Delkor Alt 1s in recently constructed or renewed track sections. Both fastener types have a specified static vertical stiffness between 18 kN/mm and 35 kN/mm. The vehicle fleet includes three vehicle types, all with solid steel wheels. Steering wheelsets minimize curving noise and wheel flats are generally rare. All vehicles use a linear induction propulsion system for traction and braking. Although some noise emission differences between train types have been observed at specific locations (switches, traction noise at stations), the differences are not consistent. In general maximum rolling noise levels between different train types and individual vehicles are very similar, with track condition the predominant influence on noise (SLR, 2018).

Noise due to rail condition and corrugation became an issue for the Vancouver SkyTrain shortly after operations commenced in 1986. Kalousek and Johnson (1992) describe some of the early investigations of the problem, reporting that adjusting wheel/rail profiles, correcting misaligned wheelsets and application of solid stick friction modifiers to the wheel treads were successful in reducing rail corrugation development.

In Vancouver rail grinding is normally undertaken to remove rail defects and correct the rail profile, not specifically to mitigate noise. If rails are not corrugated, grinding can increase rather than decrease noise. Recent investigations (SLR, 2020) have quantified the noise benefit of friction modifiers and other noise mitigation measures including the use of harder rail steels and acoustic grinding. Noise control remains a challenge on the system, with a clear pattern of noise increasing as a result of wear in the wheel/rail interface and decreasing following maintenance intervention such as rail grinding. Grinding has historically been undertaken using in-house equipment supplemented by external grinding contractors, but in 2020 contract grinding was not possible due to the pandemic. Normal grinding intervals vary from quarterly in some areas of the system with original relatively soft rails, up to every two years in the newer sections of the network with harder rails. Noise increases of 10 dBA can occur within a few months of rail grinding in some hotspots, typically on original parts of the network where the relatively soft rail steel is more prone to rapid corrugation growth than recent extensions. However, cyclical changes in noise of the order of at least 5 dB are observed network wide between grinding intervals on both curves and tangent track, and are attributed to changes in rail condition.

4.1 Vancouver passby noise measurement overview

A series of passby noise measurements were collected at 14 locations distributed around the SkyTrain network in November 2020, these locations are indicated in Figure 2.

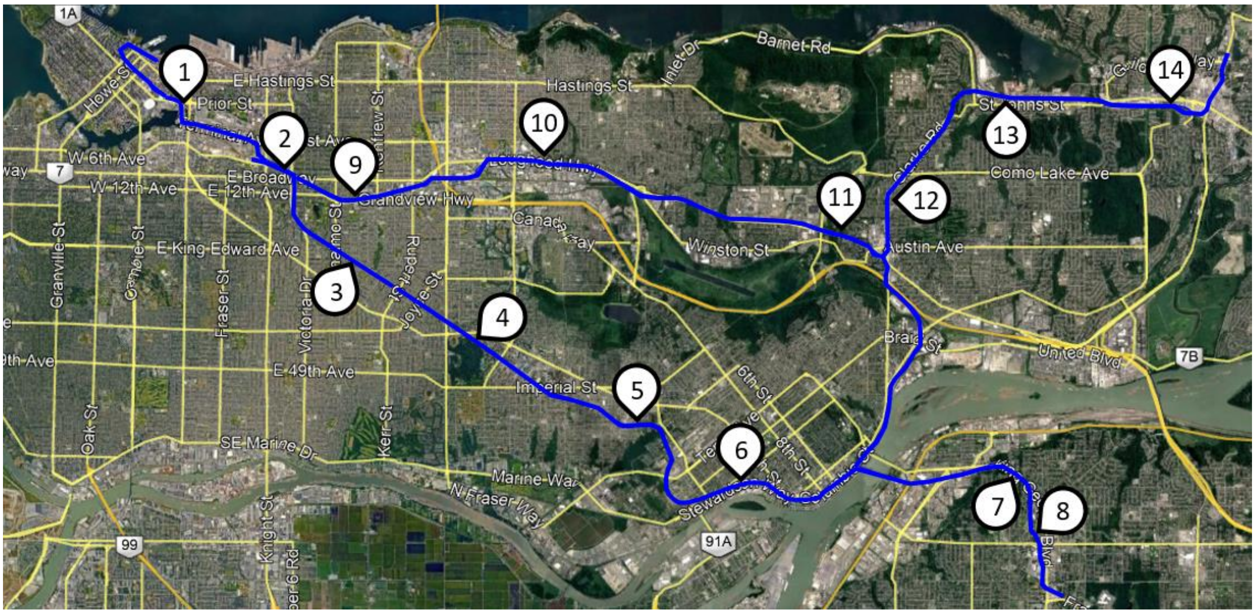

Figure 2: Noise measurement locations around the Vancouver SkyTrain Network (blue line)

Measurements used a microphone attached to a 7.5 m telescoping extension pole to enable collection of noise data from a position elevated above the guideway parapet wherever possible. Figure 3 shows an example of a typical measurement configuration. At three locations (6, 8 and 11) the guideway was higher than the maximum extension pole length, at these locations it is possible somewhat higher noise levels would be recorded at a measurement location above the parapet, particularly for the far track.

Figure 3: Example noise measurement configuration (Location 8) with microphone circled in red

4.2 Vancouver passby noise measurement results

The parameter reported is the maximum value of the sound pressure level during the passby event (L_{AFmax}),arithmetically averaged for at least 10 and up to 20 passby events in each direction, inbound (IB) and outbound (OB). The objective of the measurements was to provide a baseline for future monitoring and trends in noise over time, and to indicate the range of passby noise level observed at different locations due to variations in track condition. As a fully automated system, train speeds are very consistent, the majority of locations had operating speeds of 80 km/h. The result is very consistent measured noise levels between individual passby events, typically the L_{AFmax} difference between quietest and loudest passby event at any one location is within 3 dB.

Table 1 provides an overall summary of the measured noise levels, along with the horizontal distances from the measurement point to the track centreline and the train speeds at each location. Results shown are the average for all train types at each location. Also shown in Table 1 is a set of results that have been corrected for speed and distance, to enable direct comparison between the results at each measurement location as if all measurements had been taken at a distance of 15 m and with a train speed of 80 km/h. Noting the close proximity of the measurement points to the source line, the distance correction factor applied is $10 \cdot Log_{10}(distance/15)$. The speed correction factor applied is $30 \cdot Log_{10}(speed/80)$, since rolling noise is dominant.

Passby maximum sound levels, corrected to 15m distance and 80 km/h speed, range from 75 dBA up to 101 dBA with a median value of 83 dBA. A clear outlier in the presented data is the inbound sound level of 101 dBA at Location 6. Measured noise levels were almost 10 dB higher here than at any other testing location indicating the track in this area was in poor condition at the time of the measurements. At this location the rail in service was originally installed in 1986 and comprised relatively soft (248 HB) rail steel. This rail section had not been ground for over two years, but the fasteners had already been renewed and the rail was replaced a few days after these measurements were completed with harder steel (370 HB) as part of an ongoing rail replacement program.

The location with the lowest measured noise levels corrected to 15 m distance and 80 km/h speed in Table 1 is the inbound track at Location 12. This part of the system is on the most recent extension to the network, commencing operations in 2016. The original rail steel in this area is relatively hard, 350 HB, and newer rail fasteners are in place. The most recent grinding at this location occurred approximately 6 weeks prior to the noise measurements, so this location is expected to represent track in best possible acoustic condition with noise levels as low as practically possible. Locations 12, 13 and 14 all have 350 HB rail steel in place, in these areas the noise levels measured varied from 75 dBA up to 83 dBA, a range of 8 dB.

Table 1: Summary of measured and corrected passby maximum noise levels

Location Ref.	Distance from Track Centreline (m)		Speed (km/h)		Measured Average Passby L_{AFmax} (dBA)		L_{AFmax} (dBA) corrected to 15m and 80 km/h	
	IB	OB	IB	OB	IB	OB	IB	OB
1	11	15	65	50	83	76	85	82
2	20	24	80	80	83	80	84	82
3	19	15	70	77	81	89	83	89
4	17	21	80	80	83	77	84	78
5	28	32	77	79	85	74	88	77
6*	15	19	80	80	101	81	101	82
7	19	15	80	80	82	89	83	89
8*	17	21	70	70	90	85	92	88
9	23	27	80	80	79	80	81	83
10	28	32	80	80	81	78	83	81
11*	14	18	80	80	85	79	85	80
12	17	13	80	80	75	82	75	81
13	20	16	65	65	76	80	80	83
14	11	15	80	80	82	83	80	83

* Microphone somewhat below guideway height, possibly reducing measured levels especially on far track

Figure 4 shows the average L_{AFmax} passby noise spectrum for the inbound track at locations 6 and 12, representing the noisiest and quietest areas of the network. Train speeds are the same and the measurement offset distance is very similar. Rail fasteners at both locations are the newer Delkor type. While rail roughness was not measured directly to correspond to the noise measurements, the differences in the spectrum can be attributed almost entirely to differences in rail condition and maintenance state.

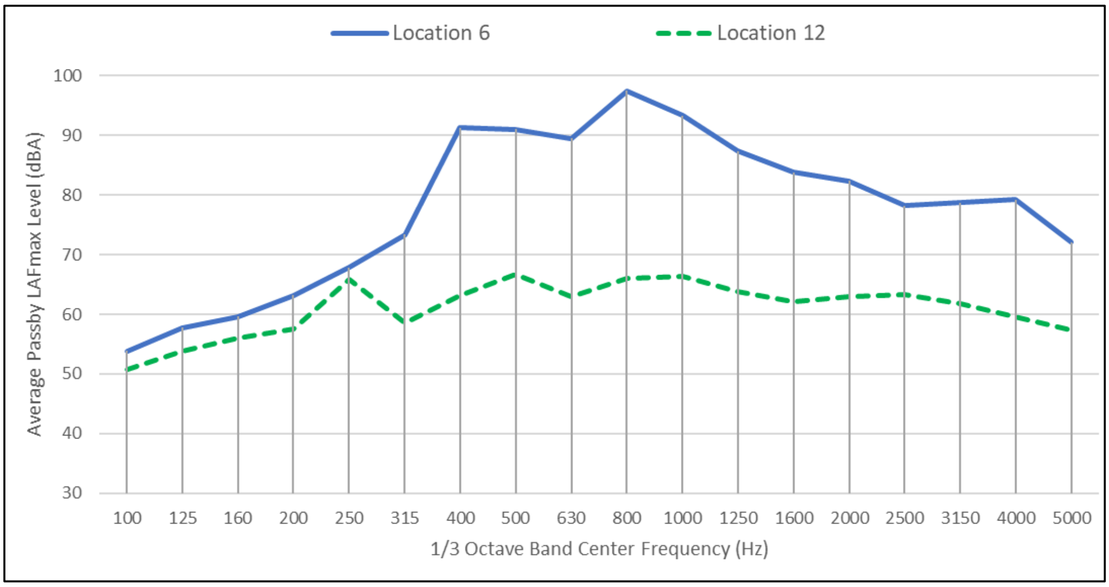

Figure 4: Comparison of passby noise spectrum at Location 6 and Location 12

4.3 Discussion of Vancouver passby noise measurement results

It is interesting to review the Vancouver measured noise levels in the context of the reference noise levels provided by the US FTA, which include approximate passby maximum noise levels. The reference passby L_{AFmax} value for rail cars operating on an aerial structure with slab track at approximately 15 m and 80 km/h (50 feet and 50 mph) is 84 dBA (FTA, 2018). This reference level is similar to the median result measured in Vancouver, but is 9 dB louder than the minimum measured noise level and 17 dB less than the highest measured noise level. The measured noise levels on the newest extension to the system were all within the US FTA reference levels.

Vancouver has identified a noise mitigation goal "to optimize maintenance practices to keep train pass-by noise emissions within 5 dB of the best case (minimum) noise" (Translink, 2021). Achieving this goal would result in noise emissions that are 4 to 9 dB less than the US FTA reference levels. While this may seem ambitious for a system exhibiting a 26 dB variation in noise levels system-wide, this goal is already achieved in some areas of the network.

The Vancouver example illustrates the importance of both system design and maintenance practices to minimise long term noise emissions from rail transit systems. Carefully selected wheel/rail profiles, use of harder rail steel and provision of friction management are all design factors that are key to controlling long-term emissions. Rail grinding and long term wheel/rail interface management / maintenance are also critical. The Vancouver example also highlights the potential risk in assuming that noise levels will consistently be able to be maintained at the minimum possible level on a high-frequency automated rail transit system with limited maintenance windows. Roughness, corrugation and associated noise issues are relatively common on metro and light rail systems worldwide, this would not be the case if effective solutions were easy to implement.

5 FINAL REMARKS

Rail roughness and rail maintenance practices such as grinding are critical factors in rolling noise generation. In NSW the potential for variation in track condition over time due to wear or maintenance interventions is rarely addressed in noise impact assessments or the design of new rail transit systems. Instead, noise impact assessments commonly assume that track will simply be maintained in good condition, and hence noise will be stable and consistent over time. This assumption has proved to be reasonable for assessment of historical heavy passenger rail projects in NSW; there are several studies confirming that rail acoustic condition does tend to be reasonably stable over time, often improving rather than deteriorating in the period following rail grinding.

Recently however, the rail infrastructure project pipeline in NSW has shifted to focus on expansions to the metro and light rail systems. On these types of systems internationally there is a growing body of evidence that rail roughness is often considerably higher than is the case on conventional heavy rail systems. Metro systems have been shown to have a particular tendency to rapid corrugation growth, in particular on curves. Light rail systems in Europe have been shown to have broadband rail roughness levels that are considerably higher than the levels corresponding to measurements in the NSW Rail Noise Database, which represent noise emission data from rolling stock operating on track in close to best case acoustic roughness conditions.

An information gap exists at present around the range of noise emissions that may occur over time with maintenance cycles on Sydney Metro and Sydney Light Rail. The addition of more measurements to the NSW Rail Noise Database would partially address this gap, since no metro measurements and relatively few light rail measurements have been included in the database to date. However, fundamentally the Database aims to identify noise emissions from different types of rolling stock. It specifically aims to report noise levels measured under standard reference conditions.This objective is inherently in opposition to the need to understand variation in noise levels over time, or the effect of track maintenance condition on noise.

It is hoped that this paper will promote understanding and discussion of the variability in noise over time with rail maintenance cycles, and approaches to address this potential noise variation. The potential for variable noise emissions is relevant and should be considered at all project stages including design, impact assessment, procurement, and operations and maintenance. In practice there is a relatively wide range of possible noise emissions over time from any combination of track and vehicle. As such, a single rail noise emission source level is not always representative.

Variable noise levels with rail condition represent both a risk and an opportunity for acousticians, rail designers, operators and maintainers. There is a risk that assessments may underpredict noise impacts. There are also opportunities to optimise operations and maintenance practices for future and existing sections of the Sydney

Metro and Sydney Light Rail networks to target long term noise minimisation, as demonstrated by recent mitigation investigations on the Vancouver SkyTrain network.

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