Assessment of rail noise based on generic shape of the pass-by time history

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ABSTRACT

Assessment of intermittent noise events is normally based on evaluation of sound pressure levels (SPLs) associated with the noise sources. Calculation of the noise contribution requires knowledge of equivalent SPLs for each of the pass-by events. It frequently involves significant efforts to extract necessary information for each of the transport pass-bys. Although it may not be difficult for rare events, it may not be appropriate for noise evaluation of frequent pass-bys, such as train traffic on a busy rail line. The estimate of noise during a train pass-by requires knowledge of the beginning and end of the event and associated equivalent SPL. Rather than estimating each individual pass-by, it is suggested to use information about generic shape of the pass-by time history and average pass-by time. The equivalent SPL can then be calculated from the knowledge of maximum equivalent SPL during the pass-by. It is relatively easy to extract this parameter after processing time histories of SPLs. Day and night time levels associated with rail noise can be calculated from information about noise levels exceeding a certain limit. The procedure was tested during a long term noise monitoring program. Information from a noise monitoring station was assessed utilising the simplified procedure and conventional post-processing. It indicates good agreement between the data and therefore potential to be employed for rail noise assessment. It may be recommended for long term monitoring programs which involve post-processing of a large volume of monitoring data.

INTRODUCTION

Railways have become a popular kind of transport for many urban densification programs. They have many positive features including, but not limited to, low greenhouse gas emission rates per passenger, and reliable commuting which does not depend on general traffic congestion.

A few Government planning initiatives are focused on mixed use of residential and commercial developments where proximity to transport corridors is one of the attractive features, providing residents an opportunity for quick and reliable commuting services within the urban area (NSW EPA, 2013, SA EPA, 2013). However such planning solutions evoke environmental challenges due to close proximity of residential developments, recreational and public areas to sources of noise pollution.

Noise and vibration from rail operations and transport corridors can cause nuisance and sleep disturbance effects for occupants of noise sensitive land uses (WHO, 1999). Reliable evaluation of the noise impacts of a rail corridor assists in making correct estimates of the noise contribution from different noise sources and facilitates development of effective planning and design solutions. This task may be complicated in a noisy urban environment with a high number of rail transport pass-bys.

The procedure of rail noise monitoring can be simplified by analysing train pass-by events on the basis of generic time history characterising such events. The relevant method is considered in this paper where only the maximum sound pressure level (SPL) of the event is utilised for assessment of the noise impact pertained to the train pass-by. It reduces the number of parameters necessary for calculation of rail noise in comparison with the conventional procedures (Standards Australia, 2002, ISO, 2005).

RAIL NOISE ASSESSMENT PROCEDURES

Regulatory requirements for rail noise measurements

Noise impact from rail is intermittent in nature. The majority of regulatory procedures require assessment and reporting of the rail noise to be done separately for each of the pass-by events. It can be done by attended or unattended noise monitoring. Attended measurements are impractical if assessment is required to be done over a long time period. Analysis of data typically includes (NSW EPA, 2013, SA EPA, 2013):

- Identification of the pass-by event and its duration;
- Estimation of A-weighted equivalent SPL over the pass-by event;
- Estimation of maximum A-weighted SPL for the pass-by;
- Calculation of day and night time rail noise levels (also evening levels in accordance with some regulations) and comparison with relevant criteria;
- Calculation of 95^{th}-percentile levels for maximum A-weighted pass-by levels (normally with "Fast" time weighting) and comparison with the applicable limit.

Implications of conventional data analysis procedures

Knowledge of the start and end of the pass-by event and the time history of the A-weighted SPL are necessary to make a correct assessment of rail noise.

Strategic noise mapping, evaluation of noise exposure for suitability of land for a particular land use, and comparison of noise levels with recommendations of the World Health Organisations (WHO) requires knowledge of long term averages of the acoustic descriptors (WHO, 2009, The European Parliament, 2002, Standards Australia, 1997). Unattended noise monitoring may be required for long term evaluation to get a sufficient amount of information, which brings estimates of the acoustical descriptors over the required period of time. In the absence of information about train pass-bys at a particular location (which is the case for many monitoring programs), combined analysis of audio records and SPL time history is required to identify the required parameters. It is a time consuming and economically inefficient process.

ALTERNATIVE RAIL NOISE ASSESSMENT DATA POST- PROCESS

The equivalent SPL for an individual train pass-by can be calculated using the formula:

$$L_{Pi} = 10\log\frac{1}{\Delta t}\int_0^{\Delta t}\frac{p^2(t)-p_a^2}{p_0^2}dt \quad , \qquad (1)$$

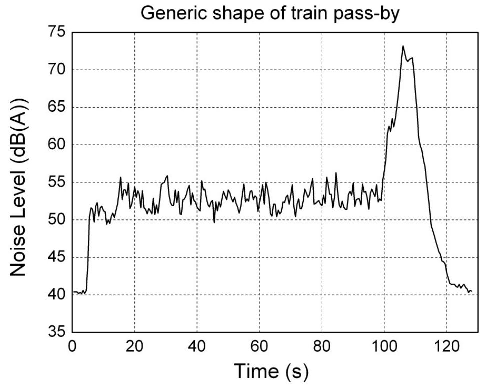
where $p(t)$ is an acoustic pressure during pass-by, p_a is an acoustic pressure from ambient sources or background and p_0 is the reference pressure of 20μPa. Change in SPL corresponding to train pass-by can be extracted from analysis of the time histories or common features of the SPL change can be utilised to simplify the process. For example, equivalent SPL of a pass-by event can be determined by:

$$L_{Pi} = 10\log\frac{1}{\Delta t}\int_0^{\Delta t} f(s_1, s_2, .., s_n)dt \, , \qquad (2)$$

where f is a generic function which depends on a limited set of parameters s number of which n is limited. Preferably parameters s should be easily extracted from the SPL time histories by an automated procedure. Ideally there should be only one parameter to detect and the others may be replaced by averages.

Features of the SPL histories during pass-bys

A simplified rail noise assessment procedure should be easier to implement for rail lines with a limited number of operating regimes and variety in the rolling stock. For example, analysis of train pass-by time histories of regular passenger trains on urban commuting lines indicates that many parameters of the SPL time histories do not vary significantly for each of the individual events. It may be connected to prescribed regimes of the train operations. The SPL variation can be divided into 3 major periods which include the signal bells and the approach of the train (Δt_1), pass-by at the close separation distance with L_{Aeq} peaking at the maximum level (Δt_2) and departure with a relatively sharp drop-off of the train noise down to the ambient level during the Δt_3 period (Figure 1a). Time history of the pass-by can be approximated by a simplified generic shape shown in Figure 1b.



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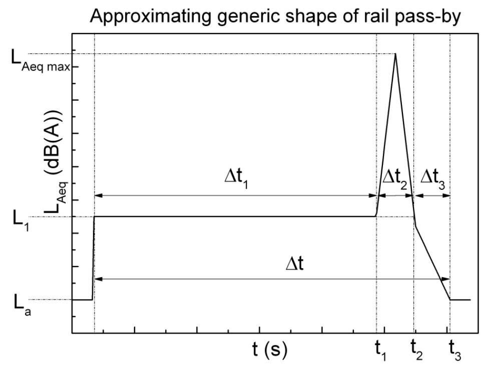

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Figure 1. *a)* Typical time history of a train pass-by and *b)* simplified shape of rail pass-by event

Equivalent SPL of individual pass-by

It was noted that the duration of the train pass-by and any of the characteristic periods within the event did not vary significantly during the monitoring. Therefore the characteristic time can be assumed constant. The ambient level in the day time is more affected by intermittent noise sources that are not characteristic of the monitoring area. It is reasonable to assume for the purpose of the calculation that the actual ambient level (L_a) can be defined from night time magnitudes relevant to the monitoring location. SPL characteristic for the approach period also did not demonstrate significant variations. Only maximum L_{Aeq} magnitudes are prone to deviate and therefore it is difficult to recommend a single average number characteristic for the train pass-bys. It can be seen from analysis of the assumptions that equivalent SPL associated with the pass-by event can be calculated if maximum L_{Aeq} is known, extraction of other parameters from the time histories is not required to calculate rail noise over a long period of time.

Based on the assumptions above, formula (1) can be represented in the form:

$$L_{Pi} = 10\log[\frac{1}{\Delta t}(\int_0^{t_1} 10^{L_1/10} dt + \\ + 2\int_{t_1}^{0.5(t_2+t_1)} 10^{(L_1+\beta(t-t_1))/10} dt + \\ + \int_{t_2}^{t_3} 10^{(L_1-\gamma(t-t_2))/10} dt) - 10^{L_a/10}] \quad (2)$$

where the relevant parameters are represented in Figure 1b. Magnitudes for β and γ can be calculated from differences in the SPL levels as follows:

$$\beta = \frac{L_{\text{Aeq max}} - L_1}{0.5\Delta t_2}, \quad \gamma = \frac{L_1 - L_a}{\Delta t_3} \quad (3)$$

The resulting formula for calculation of the equivalent SPL over a pass-by event can be derived from expression (2):

$$L_{Pi} = 10\log[\frac{1}{\Delta t}(\Delta t_1 10^{L_1/10} + \\ + \frac{20}{\beta \ln 10}(10^{L_{Aeq\max}/10} - 10^{L_1/10}) + \\ + \frac{10}{\gamma \ln 10}(10^{L_1/10} - 10^{L_a/10})) - 10^{L_a/10}] \quad (4)$$

The equivalent levels associated with the train noise for a longer period can be calculated as follows:

$$L_P = 10\log\frac{N\Delta t \sum_{i=1}^{N} 10^{L_{Pi}/10}}{T}, \quad (5)$$

where T is the entire averaging period (day, night or evening), and N is the number of pass by events during the averaging period.

CALCULATION OF RAIL NOISE OVER A LONG TERM MONITORING PERIOD

Advantage of the generic shape method

Noise measured in a typical urban environment is influenced by multiple contributors and it is difficult to extract contribution from a single source from a total noise measurement. This problem can also be attributed to the task of rail noise monitoring. Extraneous noise sources and generally high ambient noise may significantly distort L_{Aeq} time histories of train pass-bys (see Figure 2). In such situations data post-processing, based on the generic shape, brings several advantages in comparison with the conventional method.

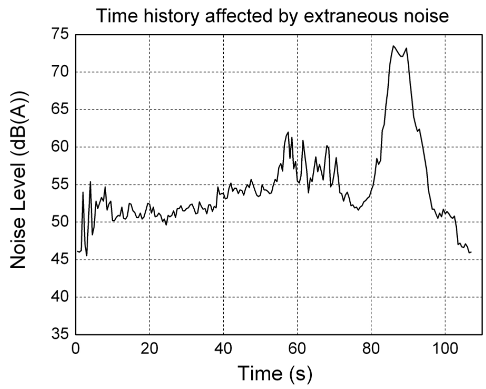


Figure 2. Generic shape distorted by extraneous noise

Long term monitoring enables analysis of the pass-by events when ambient/background noise is at the lowest magnitudes. It also allows more accurate detection of the pass-by shape and relevant parameters such as L_a and L_1 and the characteristic time intervals. The parameters in many cases can be better extracted during night time or evening periods. Day time noise levels can be significantly affected by higher ambient noise. Generally this is not related to $L_{Aeq\ max}$ magnitude. If monitoring equipment is placed at a reasonable separation distance from the rail, $L_{Aeq\ max}$ is significantly higher than noise from other sources so its magnitudes can be identified with sufficient accuracy. This is the only variable which is required for calculation of the equivalent levels associated with the pass-bys. It can be easily extracted from available L_{Aeq} time histories as magnitudes exceeding a certain level. This "trigger level" should be determined from a preliminary analysis of data pertained to the train pass-bys. It should be noted that due to generally significant difference between $L_{Aeq\ max}$ and L_a magnitudes, the latter does not have a significant influence on the pass-by levels computed by formula (4).

Noise monitoring results for a proposed transit oriented development

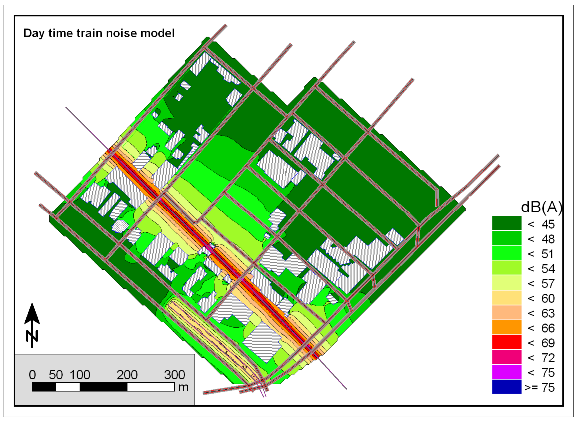
Development of one of the urban areas for residential and commercial use required estimates of rail noise impact in the zone adjacent to the city passenger railways. Commuter trains move on the rail at regular intervals during day time periods, with rare pass-bys during night periods (10pm-7am). Normally the passenger trains consist of 1 or 2 carriages. Noise monitoring of rail noise was performed using a B&K Type 3639A station over a period of a few months. There was a month's break in the rail operations during the monitoring period which enabled an estimate of the rail noise levels on the basis of differences in levels over operational and non-operational periods.

Table 1 shows day and night time estimates obtained by conventional data processing procedures, the proposed method and the difference in long term averages of SPL during periods when the rail was operational and non-operational. It shows a close match between the magnitudes, which confirms the possibility of using the proposed method for estimation of noise contribution from the rail infrastructure. Average parameters utilised for the rail noise assessment by the suggested procedure are: Δt=115s, Δt_1=94.5s, Δt_2=14s, Δt_3=6.5s, L_1=52.6dB(A), L_a=40.2dB(A). $L_{Aeq\ max}$ magnitudes for the individual pass-bys have been extracted as the single number exceeding the trigger SPL of 70dB(A) within the time window centred on the maximum.

Magnitudes assessed by the conventional procedure are marginally higher than numbers computed by the generic shape method. This could be expected due to reasons explained in the previous section, i.e. an actual SPL time history includes a higher contribution from other noise sources.

Table 1. Comparison of rail noise magnitudes calculated from noise monitoring data using different methods

$L_{Aeq,}$dB(A)	$L_{Aeq,}$ Day	$L_{Aeq,}$ Night
Conventional procedure	53.6	49.3
Generic shape method	52.7	48.4
Oper-tional/Non-operational	55.5	46.1



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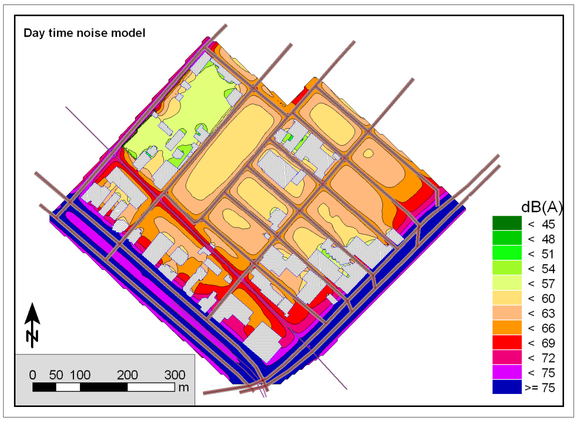

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Figure 3. Predicted day time L_{Aeq} in the area: *a)* rail noise source only, *b)* all sources

The data have been utilised for prediction of the rail noise in the affected area and for comparison of the impact with overall noise. A SoundPlan model was utilised to produce a noise map of the area on the basis of data from a network of monitoring stations deployed in the zone.

The number of train movements during night time hours is limited so the night time levels were not critical for the development in terms of meeting regulatory and planning requirements. Figure 3a indicates that rail noise comfortably complies with requirements in the SA Guidelines for Assessment of Noise from Rail Infrastructure (SA EPA, 2013) at separation distances of approximately 30m or more (60dB(A) criterion for new residential developments, day time). The necessary buffer can be reduced by implementing noise mitigation measures. The impact of rail noise on a proposed development is significant up to about 60m from the rail line. At greater separation distances, it is more influenced by other noise sources (Figure 3).

SUMMARY

An alternative method to calculate rail noise impact from collected long term monitoring data is proposed. It is based on an assumed generic shape of a train pass-by and relevant average parameters except for the maximum SPL during the event. The method provides a tool for a more accurate estimation of rail noise in an environment with high ambient noise or where the measurements are affected by extraneous noises. This is especially important for noise monitoring programs in urban environments.

The method was tested on the basis of data collected during a long term noise monitoring program in an area intended for an urban mixed use development. The long term averages of the rail noise impacts have been estimated by the conventional method, generic shape method and by comparing data for periods when the rail line was operated and when there was an outage in the rail operations. The estimates indicate good agreement and thus potential for implementing the proposed procedure for long term monitoring projects. It does not require thorough analysis of individual train movements and mainly involves extraction of the maximum noise levels pertained to the pass-bys. This information can be easily extracted from the monitoring data.

REFERENCES

International Organization for Standardization 2005, *Railway applications – Acoustics- Measurement of noise emitted by railbound vehicles*, ISO 3095:2005, International Organization for Standardization, Geneva.

NSW Environment Protection Authority 2013, *Rail infrastructure Noise Guidelines*, NSW EPA, Sydney.

SA Environment Protection Authority 2013, *Guidelines for the assessment of noise from rail infrastructure*, SA EPA, Adelaide.

Standards Australia 1997, *Acoustics- Description and measurement of environmental noise. Part 3: Acquisition of data pertinent to land use*, AS 1055.3-1997, Standards Australia, Sydney.

Standards Australia 2002, *Acoustics–Methods for the measurement of railbound vehicle noise,* AS 2377–2002, Standards Australia, Sydney.

The European Parliament 2002, *Directive 2002/49/EC relating to the assessment and management of environmental noise*, The European Parliament and the Council of European Union, Official Journal of the European Communities, 2002.

World Health Organization 1999, *WHO Guidelines for Community Noise*, WHO, Geneva.
World Health Organization 2009, *Night Noise Guidelines for Europe*, WHO, Copenhagen.