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A geometric method to determine feasible noise barrier locations

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ABSTRACT

Feasibility and reasonableness of noise barriers are terms commonly found in road traffic noise management protocols of various road authorities. They arise in road traffic noise management in recognition that is not always possible to build a noise barrier that attenuates road traffic noise to be within project criteria at all noise sensitive receivers. Feasibility is related to engineering perspectives such as safety (for example, road users, pedestrians and cyclists), maintenance, space limitations, drainage, road access locations, locations of services and structures and most importantly topography. Reasonableness reviews the practicality of a noise barrier under site specific circumstances and includes data from acoustic assessments, cost considerations, community consultation and aesthetics of the streetscape. This paper does not consider reasonableness. The feasibility test must be passed prior to consideration of reasonableness and this paper presents a geometric method which can be used during the acoustic assessment and road design process to assist in determining feasible locations for noise barriers. The use of such a method during the road design process will improve road geometries to assist in road traffic noise management. This paper reviews, (a) the acoustic fundamentals of noise barrier design, (b) some structural engineering aspects of noise barrier design, (c) combined effects on noise barrier location from acoustics, structural engineering and road design perspectives; and (d) the proposed geometric method of determining a noise barrier feasibility rating followed by some examples..

1.0 INTRODUCTION

Feasibility and reasonableness of noise barriers are terms commonly found in road traffic noise management protocols of various road authorities. They arise in road traffic noise management by recognition that is not always possible to build a noise barrier that attenuates road traffic noise to be within project criteria at all noise sensitive receivers. Examples of feasibility and reasonableness definitions can be found in the New South Wales Government, RTA Environmental Noise Management Manual [1] and Queensland Government Road Traffic Noise Management: Code of Practice [2]. This paper only considers the aspect of feasibility through analysis of acoustic fundamentals and geometry with an engineering design focus.

Feasibility is related to engineering, that is, the ability to build a noise barrier from an engineering perspective. Engineering perspectives which affect the feasibility of noise barriers include safety (for example, road users, pedestrians and cyclists), maintenance, space limitations, drainage, road access locations, locations of services and structures and most importantly topography. The feasibility test must be passed prior to consideration of reasonableness.

Reasonableness reviews the practicality of a noise barrier under site specific circumstances. A reasonableness test includes data from acoustic assessments (for example, noise barrier height optimisation), cost considerations, community consultation and aesthetics of the streetscape. This paper and the proposed feasibility rating method does not consider reasonableness.

This paper focuses on the development of a method which can be used during the road design process to assist in determining feasible locations for noise barriers. It can be used by road designers or acoustic designers. Road designers using the method as part of standard road design techniques will bring forward the noise barrier design process and thus improve the role and understanding of noise in road design. In some cases the method will induce improved road geometries to assist in road traffic noise management. Acoustic designers using the method will also improve communication of road traffic noise management needs with the road designers.

This paper firstly reviews the acoustic fundamentals of noise barrier design in Section 2. Section 3 describes the structural engineering aspects of noise barrier design. The combination of acoustics and structural engineering of noise barriers and how this effects noise barrier location in a road design are discussed in the fourth section. The variables and the method of feasibility rating are presented in the fifth section and examples are provided in the sixth.

2.0 ACOUSTICS OF NOISE BARRIERS

Sound travels in wave patterns away from a source, and its intensity diminishes with increasing distance from the source. Extra propagation attenuation occurs when a barrier is inserted into the propagation path of a sound wave. This extra propagation attenuation can be calculated from a number of methods, the most common using the variable 'path difference' in metres and this is demonstrated in Figure 1.

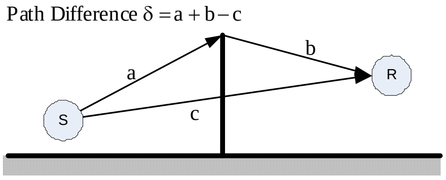

Figure 1: Path difference due to a noise barrier (S= Source, R = Receiver)

Over the years, several equations have been developed for the calculation of noise barrier attenuation in the units of decibels. The method outlined in ISO9613 [3] contains a succinct algorithm (Equation 1) for the calculation of attenuation in decibels (D_z). The variables in this algorithm are the path difference (δ), wavelength (λ), ground reflection factor (C_2), single or double diffraction factor (C_3) and meteorological correction factor (K_{met}). Feasibility assessments do not require detailed acoustic calculations and therefore Equation 1 can be used consistently across all projects with a number of defined assumptions. For feasibility analysis the ground reflections should be included in the assessment, thus in this situation ISO9613 [3] states that $C_2 = 20$. Also, only single diffraction needs to be considered in a feasibility assessment, thus $C_3 = 1$. Finally, feasibility analysis does not need to take meteorological assessment into account (this will be done later in reasonability analysis through detailed acoustic assessment) thus $K_{met} = 1$. These assumptions reduce Equation 1 to a more simplified version based on path difference (δ) and wavelength (λ) only (Equation 2). Some generic design rules which arise from inspection of Equation 1 are: (1) the highest point of intervening ground between a source and receiver is generally the best place from an acoustic perspective provided that it can provide the greatest path difference; and (2) for the same height noise barrier a location closer to the source or receiver is better than a location midway between the source and receiver; and (3) noise barriers are more effective when they cut line of sight between the source and receiver; and (4) a noise barrier that cuts line of sight provides 5 dB attenuation in all frequencies.

$$D_z = 10\log_{10}\left[3 + \left(\frac{C_2}{\lambda}\right) C_3\ \delta\ k_{met}\right]\ \text{dB}$$

Equation 1: ISO9613:2 Barrier attenuation algorithm

$$D_z = 10\log_{10}\left[3 + \left(\frac{20}{\lambda}\right)\ \delta\right]\ \text{dB}$$

Equation 2: ISO9613:2 Simplified barrier attenuation algorithm for feasibility investigations

$$D_{zavg} = \frac{\sum_{125\text{Hz}}^{2000\text{Hz}} 10\text{Log}_{10}\left(3 + \left(\frac{20}{\lambda}\right)\delta\right)}{5}$$

Equation 3: Definition of D_{zavg}: Average attenuation over 5 octave bands - 125 Hz to 2 kHz where $\lambda = 343\text{m}^{-s}/\text{Frequency}^{\text{Hz}}$ (for example, $\lambda_{250\text{Hz}} = 343\ \text{m}^{-s}/250^{\text{Hz}} = 1.372\text{m}$)

The attenuation performance of a noise barrier is highly frequency dependent, and road traffic noise emissions cover a wide audible spectrum. Generally however, a large amount of the sound energy will be within the 125 Hz to 2 kHz octave bands. In a feasibility analysis, comparative performances between alternative barriers are required and thus a single number attenuation rating in decibels is more pragmatic than assessing performance at each frequency. This paper defines the average attenuation, D_{zavg} for this purpose (Equation 3).

Noise barriers do provide small amounts of attenuation when their top edge is just below the point where line of sight is cut. However in this method, to be feasible, a noise barrier also needs to remove line of sight to the source. In road traffic noise, the height of the noise source above the pavement depends on the component noise for example, tyre/road interface is at pavement level, engine noise will typically be 0.5m to 1.0m and some heavy vehicles have exhausts positioned above 2.0m. The line of sight provisions in this method should be based on the policies of the administering road authority. Likewise, a road authority policy will determine the appropriate location for a receiver, for example, mid window height or top of window or standing level in a backyard and so on.

Noise barrier attenuation using Equation 2 and Equation 3 is plotted in Figure 2 along with a proposed noise barrier attenuation rating scheme which may later be used to determine reasonableness (in a future study) in further comparing the relative benefits of two or more noise barrier options. Figure 2 demonstrates the usefulness of D_{zavg} in feasibility analysis in that it roughly corresponds to attenuation at 500Hz with positive noise path differences but attenuation sharply drops with negative path differences. This supports the intention that noise barrier which do not cut line of sight very quickly becomes unfeasible.

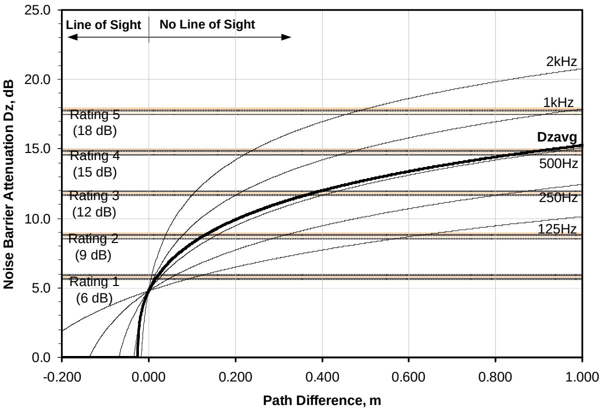

Figure 2: Noise barrier attenuation using Equation 2 and Equation 3

3.0 NOISE BARRIER & ROAD DESIGN PROCESS

The industry process of designing noise barriers tends to become very iterative and thus inefficient and potentially costly. Acoustic assessments tend to be initiated well after a road design is near completion and thus acoustic design practices have limited input into the early crucial decisions made on the roads horizontal and vertical alignment. Additionally, original project cost estimates may underestimate the need of acoustic attenuation design and the ancillary road side furniture or structures required to accommodate noise barriers for example; crash protection, drainage structures and flow paths or retaining walls or the location of services.

Acoustic consultants usually have limited road design knowledge and will aim to locate noise barriers in the most acoustically efficient location such as the lowest noise barrier height. Having limited road design knowledge means the acoustic consultant relies on or may be influenced by a road designer to specifically locate a noise barrier in a location which results in less than ideal noise barrier design (structurally and aesthetically). The acoustic consultant generally has limited influence on the road design at this stage and it can be difficult to communicate a preferred design outcome to the road designer. The road designer can be unwilling to introduce significant alterations to the road design due to cost and time limitations and the level of rework required.

A road designer will tend to not consider road traffic noise in the early parts of a road design project and rather wait until later stages for advice from an acoustic consultant about the need for noise attenuation and then the type of attenuation for example, height of a noise barrier wall. Whilst waiting for the acoustic design recommendations, the detailed design can easily progress to a point where alignment changes (vertical and horizontal) are very difficult to implement, thus introducing a conflict between the road design and the acoustic design. This means good acoustic design practice through road design is not as efficient as it could be if the road designer were able to assess feasibility at an earlier stage in the road design process.

Figure 3 demonstrates a current design process which is commonly found in industry. Feasibility analysis (judgemental, formal or informal) is left until after the acoustic recommendations are received from the acoustic consultant and the road design is essentially completed. This introduces the high probability of iterative design loops with road design modifications or acoustic reassessment or both simultaneously.

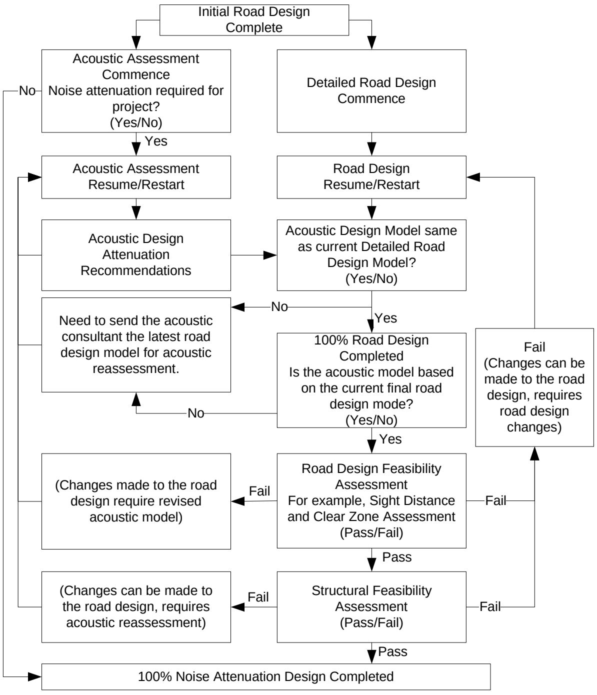

Figure 3: Current industry design process for noise barriers

Figure 4 demonstrates the design process proposed in this paper to support the introduction of a standardised noise barrier feasibility assessment. The notable difference to Figure 3 is that the feasibility analysis is completed initially by the road designer prior to the detailed acoustic assessment. Whilst it appears that the proposed process includes additional steps, it is predicted that significant project costs and efficiencies will arise by avoiding the multiple design process loops currently experienced. The implementation of a robust and standardised feasibility analysis conducted by the road designer and also verified by the acoustic consultant will improve communication between the two different professions. The road designer is also capable of significantly improving project cost assessments. Most importantly, early identification of potential problem areas for acoustic design allows a road designer to make early changes to a horizontal and vertical alignment to improve noise barrier feasibility and noise barrier locations.

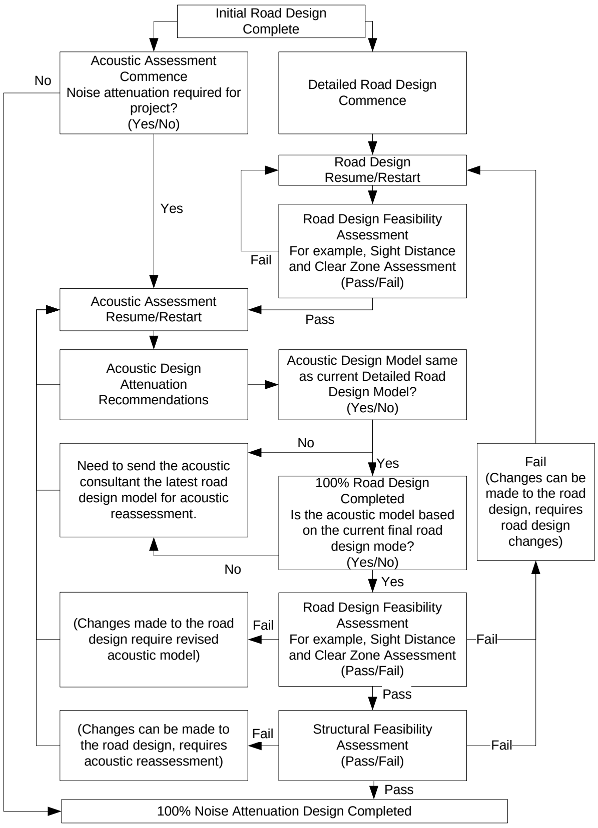

Figure 4: Preferred industry design process for noise barriers

4.0 NOISE BARRIER FEASIBILITY VARIABLES

A road designer must consider two main safety parameters related to noise barriers in a road corridor, being (1) sight distance; and (2) clear zone.

Regarding sight distance, a noise barrier can limit sight distance if it is located too close to the road carriageway, particularly on the inside of a horizontal curve. A road designer is required to confirm that sight distance is maintained after the final acoustic design of the noise barrier is made, however significant project time savings could be made if sight distance is investigated prior to acoustic assessment. This requires a road designer to move noise barrier considerations forward in the design process and a feasibility method is required for this to occur.

Regarding the clear zone, noise barriers are significant structures and can be hazardous structures to errant vehicles when located in certain places in the road corridor. Therefore if they are located within the clear zone of a roadway, errant vehicles need protection from striking these structures through the installation of crash barrier protection. The presence of crash barriers introduces additional design options and constraints for noise barrier design, such as the option to place noise barrier panels on top of concrete crash barriers or noise barriers needing to be a set distance behind w-beam guard rail.

There are other issues in the road design process which need consideration such as drainage paths and drainage structures, overhead and underground services, pedestrian and cycle paths and safety.

A structural engineer involved in the design of the noise barriers is interested in geotechnical data of the noise barrier location, wind zone category (for example: cyclone zone, dense built environment or mountainous), vandal resistance, panel and post material and design properties. However the most important issue for feasibility analysis from a structural design perspective is the slope of the ground where the noise barrier footing is to be positioned. A flat surface is better for maintenance and equalised foundation load on both sides of the barrier, yet barriers can be constructed on slopes up to (1 vertical to 1 horizontal) but no more than (1 vertical to 2 horizontal) is preferred.

Taking into consideration the acoustics of noise barrier attenuation and road design, to be feasible at a specific location a noise barrier:

1. must not exceed the project design maximum noise barrier height guideline. (This is the height specified in a road project or road planning project documentation. Most road authorities tend to limit noise barrier heights to around 6.0m however there are many instances when lower or higher barriers are acceptable. The minimum noise barrier height tends to be around 2.0m for practicality reasons. The maximum noise barrier height is based on the vertical height above the terrain and consequently does not prevent the analysis of partial enclosures or curved barriers and the location of their diffracting edges.).
2. must cut line of sight with at least the project design maximum noise barrier height, that is, path difference is positive.
3. must not be built on terrain slopes greater than 100% (1 vertical to 1 horizontal).
4. must not limit road sight distance requirements.
5. must be able to be protected in the clear zone.

Feasibility design considerations used to rank the suitability of noise barrier locations between the source and the receiver are:

1. the distance behind guard rail (1.5m on existing roads and 2.5 m on new roads)
2. the presence of a concrete crash barrier (pre-cast or cast in-situ) and whether it is possible to place a noise barrier on top of the concrete crash barrier.
3. when noise barriers are within 4.0m of the lane edge line additional structural loading is required and therefore a penalty applies within this distance.

Feasibility zones or limitation zones can be applied also, for example:

1. Feasibility only commences after the farthest lane edge line is passed (this prevents barriers being located in the median strip).
2. Feasibility ceases after the nearest property boundary or road reserve boundary has been crossed.
3. Exclusion zones, that is, rivers, creek beds, conservation zones, vital immovable services can be included to limit feasibility.

These design rules can be used to develop computer software which can automatically determine the noise barrier feasibility at selected points between a source and a receiver. However all these variables need to be combined into a single number rating system for easier dissection of information and design process.

5.0 NOISE BARRIER FEASIBILITY RATING

A single number rating system has been developed for determining preferred locations for noise barriers between a source and receiver based on a given topography and other road design constraints. The rating is defined as a Feasibility Rating (FR) in this paper.

The FR proposed in this paper has been designed so that if needed it can be calculated by manual methods, however it is more appropriately implemented into computer code so that complex terrain and source and receiver geometry can be analysed. This paper does not go so far as to suggest the exact software code implementation.

$$FR = D_{Zavg\_NBmax} W_{Dist} W_{Slope} W_{LOS} W_{4.0m} W_{sd} W_{rd}$$

Equation 4: Feasibility Rating (FR) for noise barriers

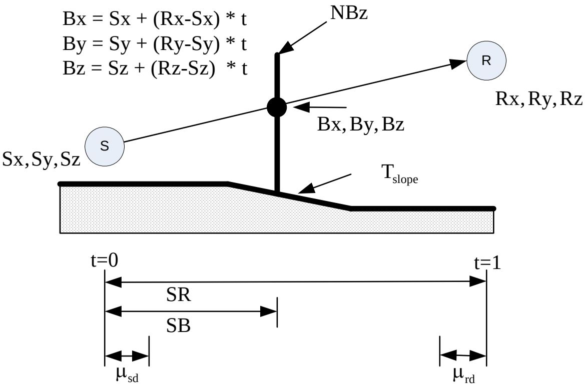

Figure 5: Geometric inputs to Feasibility Rating calculation

The FR is a multiplication of a number of variables as shown in Equation 4 and geometrical terms as shown in Figure 5. In order to compare the feasibility of different locations between a source and receiver the designer needs to define a project specific noise barrier height maximum (NB_{max}). If a road authority has produced a road traffic noise management strategy across a regional area it may include guidance on noise barrier height limits . As mentioned above, road authorities tend to aim to limit noise barriers to 6.0m in height. The first term of the FR is the D_{zavg_NBmax} Equation 5 which is the same as Equation 3 but calculated using the maximum noise barrier height guideline for a project. The second term, W_{Dist}, is a weighting factor described by Equation 6 and Figure 6 which gives increased feasibility the closer a noise barrier is to a source or receiver. Feasibility at the midpoint between a source and receiver has the lowest weight according to W_{Dist}.

$$D_{Zavg\_NBmax} = \frac{\sum_{125Hz}^{2000Hz} 10\mathrm{Log}_{10}\left(3 + \left(\frac{20}{\lambda}\right)\delta\right)}{5}$$

Equation 5: Feasibility Rating (FR) D_{zavg_NBmax} component

The third term, W_{Slope} is a weighting factor that increases feasibility for flat ground and makes feasibility nil when ground slopes exceed 45 degrees. The fourth term, W_{LOS}, is a discrete multiplier which makes feasibility possible only when the noise barrier removes line of sight from the receiver to the source (Equation 8). The fifth term, $W_{4.0}$, is introduced to reduce feasibility of noise barriers by ¼ when the noise barrier is within 4.0m distance from the source (Equation 9). The sixth term (Equation 10) and seventh term (Equation 11) are discrete multipliers which make feasibility only possible when noise barriers are beyond user input distances away from the source or receiver. For example, when μ_{rd} from

Equation 11 is 3.0m then $W_{rd} = 0$ for all locations within 3.0m of a receiver resulting in FR = 0 for all such locations. The resulting equation for FR is shown in Equation 12.

$$W_{Dist} = \left[0.83\left(\frac{SB}{SR} - 0.6\right)^2 + 0.7012\right]$$

Equation 6: Feasibility Rating (FR) W_{Dist} component

$$W_{Slope} = \left[\frac{\left(-10\left(T_s^{\,2}\right) + 10\right)}{10}\right]$$

Equation 7: Feasibility Rating (FR) W_{Slope} component

$$W_{LOS} = \begin{cases} \text{Source Visible} & 0 \\ \text{Source Not Visible} & 1 \end{cases}$$

Equation 8: Feasibility Rating (FR) W_{LOS} component

$$W_{4.0m} = \begin{cases} SB < 4.0\text{m} & 0.75 \\ SB \geq 4.0\text{m} & 1 \end{cases}$$

Equation 9: Feasibility Rating (FR) $W_{4.0m}$ component

$$W_{sd} = \begin{cases} d < \mu_{sd}\ \text{m} & 0 \\ d \geq \mu_{sd}\ \text{m} & 1 \end{cases}$$

Equation 10: Feasibility Rating (FR) W_{sd} component

$$W_{rd} = \begin{cases} d < \mu_{rd}\ \text{m} & 0 \\ d \geq \mu_{rd}\ \text{m} & 1 \end{cases}$$

Equation 11: Feasibility Rating (FR) W_{rd} component

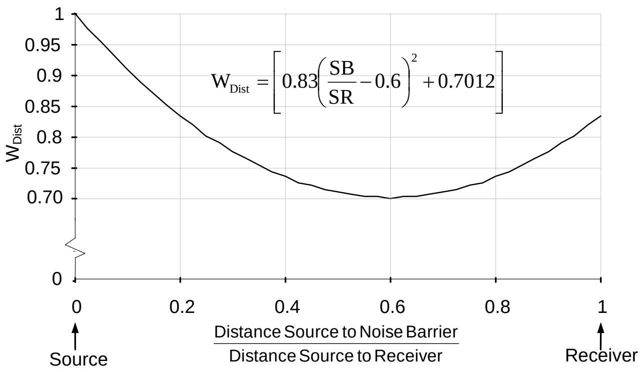

Figure 6: W_{Dist} graph

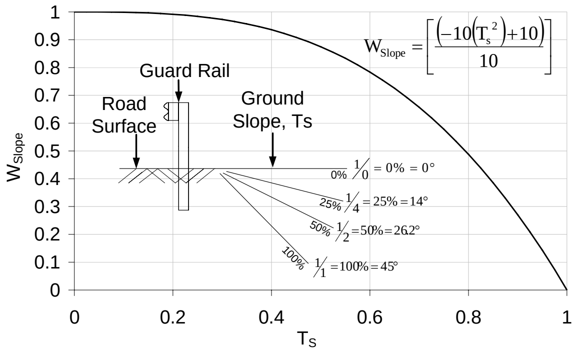

Figure 7: Ground slope, T_S, and its various possibilities

$$FR = \left[\frac{\sum_{125\text{Hz}}^{2000\text{Hz}} 10\text{Log}_{10}\left(3 + \left(\frac{20}{\lambda}\right)\delta\right)}{5}\right]\left[0.83\left(\frac{SB}{SR} - 0.6\right)^2 + 0.7012\right]\left[\frac{\left(-10\left(T_s^{\,2}\right) + 10\right)}{10}\right] W_{LOS} W_{4.0m} W_{sd} W_{rd}$$

Equation 12: Feasibility Rating (FR)

6.0 EXAMPLES

The proposed feasibility rating method was used on some realistic but simplified road and receiver geometries with varying intervening topography. In total, six examples are presented in Figure 8 to Figure 13 inclusive. These figures demonstrate the different topography and the resultant calculated feasibility rating for a 6.0m noise barrier height limit. Each example includes a high set house with two receivers representing the ground (R1) and upper (R2) floor level that are receiving noise from a single road source (S1). The example locates S1 at 0.5m above the pavement surface at the centreline of a two lane road (no median and each lane is 3.5 m wide). The property boundary of the house is 3.0m away from the receivers (R1 and R2) in all examples. In all examples μ_{sd} = 4.0m and μ_{rd} = 3.0m.

Example 1 demonstrates topography where the house is significantly higher than the road and the intervening ground is generally lower than the road. Figure 8 shows that feasibility is highest near the lane edge line and is not feasible between approximately 16.0m and 23.0m from the source for both high set and low set receivers. Noise barriers are not feasible for R2 (high set) receivers between 10.0m and 26.0m, which demonstrates the significant differences in feasibility which result from varying receiver height and dwelling heights. Feasibility notably reduces on the small embankment off the road shoulder.

Example 2 (Figure 9) represents topography where the road is located on a significantly raised embankment (natural or fill) and the house is lower than the road but higher than the intervening ground. This topography typically represents development in a flood plain. Feasibility exists everywhere between 4.0m and 27.0m between source and receiver except on the steep road embankment (approx. 6.0m to 8.0m). Feasibility is highest close to the lane edge line. Feasibility for R2 (high set) is notably lower than for R1 (low set) receivers.

Example 3 (Figure 10) shows a road in a small cut situation which establishes an earthen bund between the road and the receiver. The situation may also represent a purposely placed earth mound for noise attenuation or aesthetic purposes. Feasibility exists everywhere except between 7.5m and 10.0m where the bund slope is greater than 45°. Feasibility is slightly higher near to the road but similar levels of feasibility are observed across the top of the mound. This situation reminds us that feasibility is different to reasonableness, because a reasonableness assessment would likely conclude that a noise barrier on top of the mound is the most acoustically efficient choice. Close to the property boundary there is a larger difference in feasibility between R1 and R2 than there is across the top of the mound.

Example 4 (Figure 11) shows that feasibility exists between a source and receiver where intervening topography exhibits gradual slopes. This situation shows a road higher than the intervening ground and a receiver. For R1 (low set) feasibility is highest near the road and increases as the noise barrier location approaches the receiver property boundary, however feasibility for R2 (high set) does not increase near the property boundary.

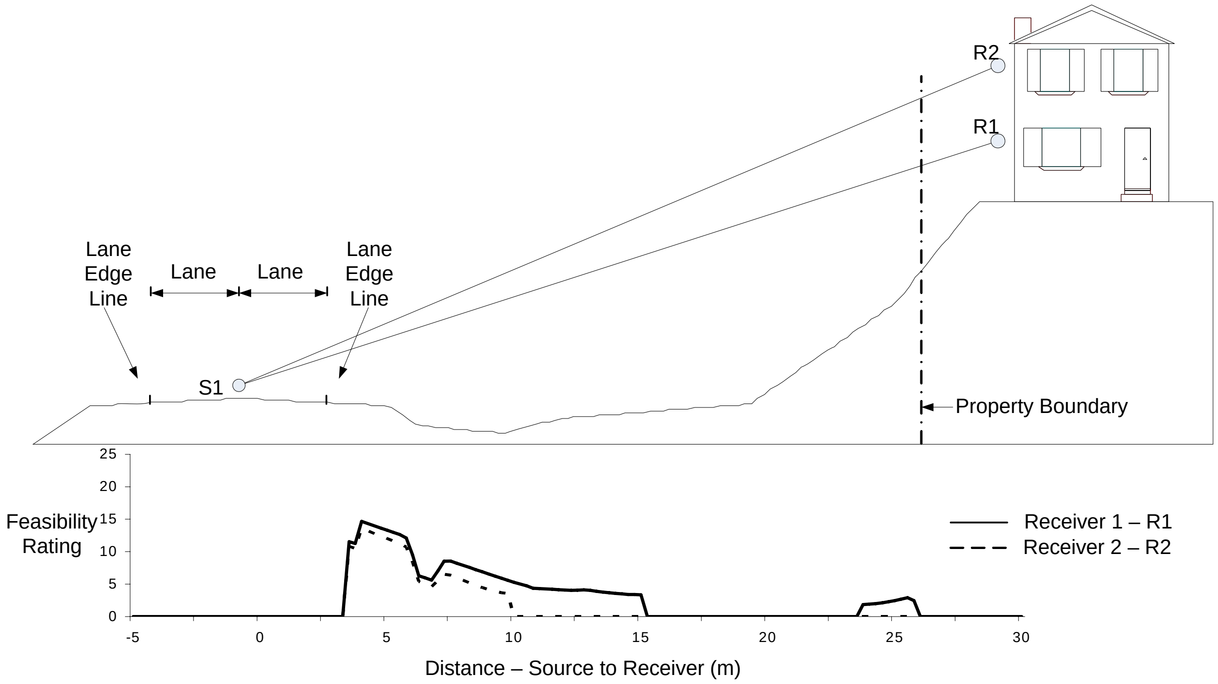

Figure 8: Example 1

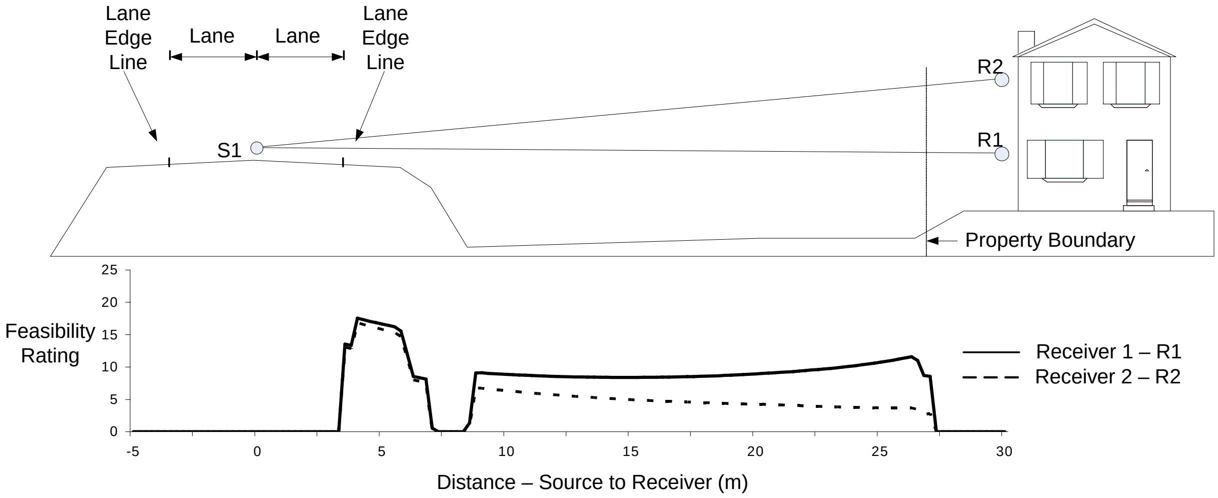

Figure 9: Example 2

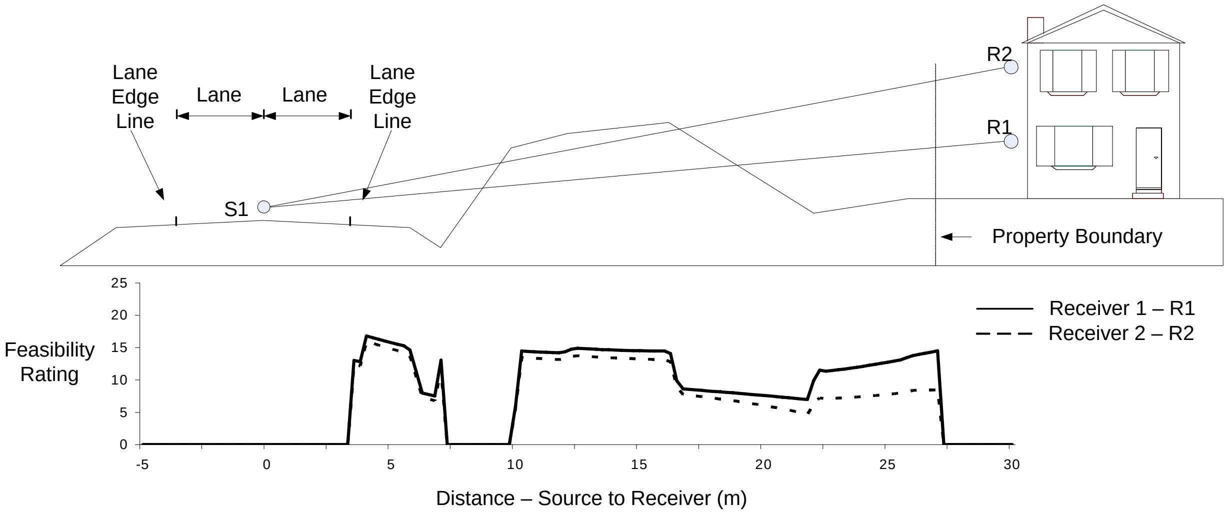

Figure 10: Example 3

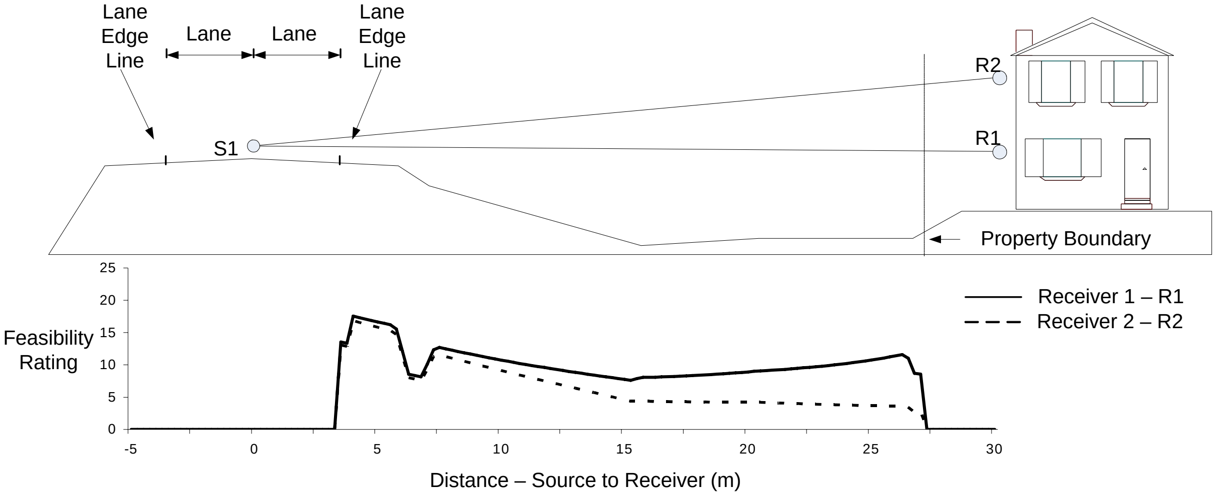

Figure 11: Example 4

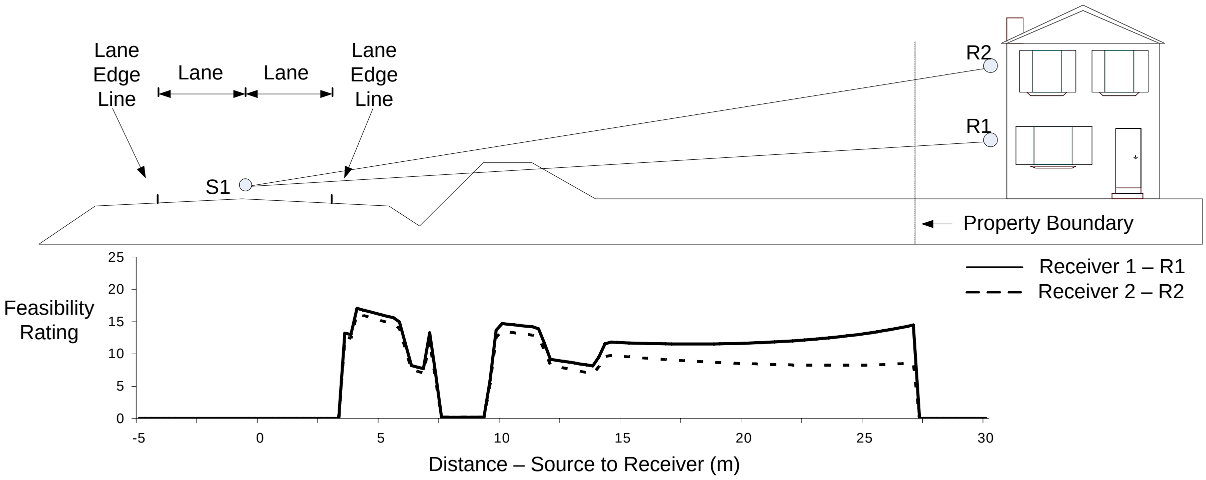

Figure 12: Example 5

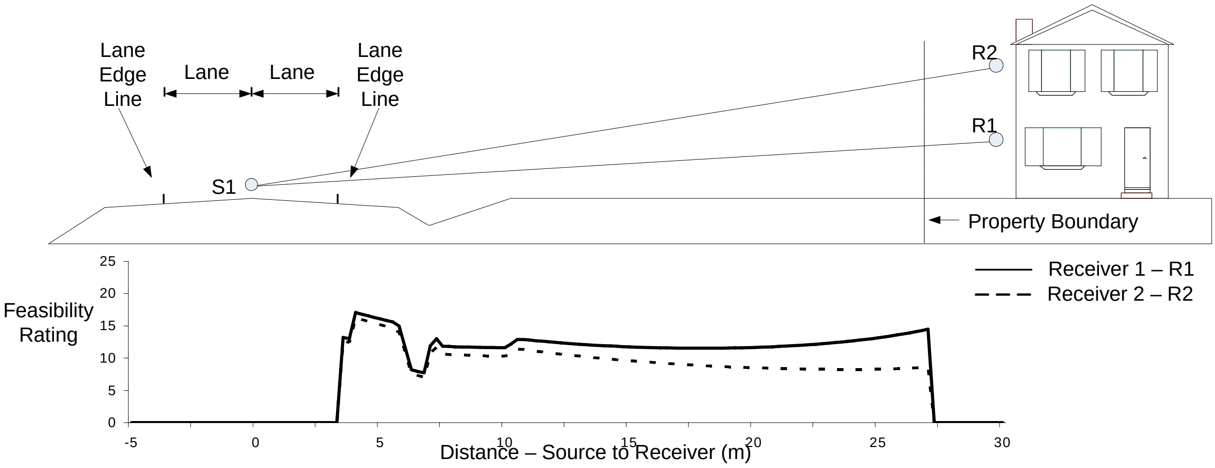

Figure 13: Example 6

Example 5 (Figure 12) is a situation where the road and building ground level are at the same level and the intervening topography includes a purpose designed earth mound. The feasibility chart shows that feasibility is nil between 7.5m and 9.0m when the slope of the earth mound is greater than 45°. Feasibility is high for both R1 and R2 near the road, however the next highest feasible location for both R1 and R2 is on top of the earth mound. However R2 feasibility is much lower than for R1 at the property boundary.

The final situation in Example 6 (Figure 13) demonstrates flat ground with a small drain near the road edge. Feasibility across the distance between source and receiver is reasonably constant as expected, except that the effect of the W_{Dist} term is clearly noticeable. Like all the previous examples, feasibility becomes lower at the property boundary for R2 compared to R1, which in this case ensures that the most feasible locations for noise barriers are along the road edge or the top of the drain on the receiver side (Distance = 10.0m)

7.0 CONCLUSIONS AND FUTURE WORK

This paper presents a geometric method on which noise barrier feasibility can be determined. The method can be used by an acoustic designer or a road designer. The Feasibility Rating will allow enhanced communication of road traffic noise management issues into the design of roads. Consequently it is expected that significant time and cost savings can be created by conducting a noise barrier feasibility assessment early in the road design process.

Future work includes imbedding the Feasibility Rating method into computer software, such as an add on to a road design software package. Once included into software, the full benefits of this proposed feasibility method can be explored. Also, once feasibility of noise barriers is embedded into the road design process, further discussion and methods can be developed on noise barrier reasonableness.

REFERENCES

1. RTA, RTA Environmental Noise Management Manual. 2001.

2. Queensland Department of Transport and Main Roads, Road Traffic Noise Management: Code of Practice - Interim Version. 2008.

3. ISO9613-2, ISO9613-2 Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation. 1996.

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