IMPLICATIONS OF ROUNDING IN HIGHWAY NOISE ANALYSES AND POLICIES

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ABSTRACT
In performing noise analyses, noise measurement equipment and noise predictive models usually report noise levels in tenths of a decibel. Customarily, these levels are reported as whole decibel numbers in state highway agencies' noise reports. However, there is not a consistent rounding method among SHAs that is applied to these levels in noise level calculations, in noise abatement feasibility and reasonableness evaluations, and in the reporting of results in SHA noise study reports. The objective of this paper is not to recommend one method of rounding. Rather, it is to discuss the influence that several different rounding methods may have on decisions regarding the feasibility and reasonableness of noise abatement devices, and to offer recommendations and suggestions for SHAs to consider when determining the number of impacted receptors, calculating a noise barrier's insertion loss, determining the number of benefited receptors, weighting benefited receptors, addressing noise reduction design goals, and calculating cost-benefit values. The paper presents nine recommendations for consideration by SHAs, and suggests rounding-related factors for consideration by SHAs in the modification of any noise policy or guidance document.

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Introduction

In performing noise studies, noise measurement equipment and the Federal Highway Administration (FHWA) Traffic Noise Model (FHWA TNM) report noise levels in tenths of a dB(A). However, FHWA and the vast majority of State highway agencies (SHAs) require or encourage the use of noise level values that are rounded to the nearest whole number in noise reports.

SHAs typically report absolute noise levels as A-weighted noise levels (dBA or (dB(A)). While many SHAs also use dBA or dB(A) in describing the differences between two noise levels, the differences between the A-weighted noise levels are not A-weighted, and the technically correct way to express such differences is by use of the term “decibel” or “dB”. Therefore, in this paper the term “dB(A)” is used to describe noise levels and the term “dB” is used to describe the difference in noise levels.

The Problem

Regarding the use of rounded or unrounded noise level values in noise studies and analyses, there exists a lack of information and direction in the vast majority of SHA noise policy and guidance documents. While most SHAs typically describe noise criteria levels in whole numbers, only about 23 percent provide instructions regarding the use of rounded or unrounded values in their noise studies and noise analyses and only a small fraction of this 23 percent discuss the SHA’s rounding method and rounding convention related to all relevant values associated with noise levels, equivalent receptors, etc. The remaining 77 percent do not address the topic of rounding at all, even though a cursory review of a few noise studies performed for these SHAs indicated that noise consultants did employ rounding in their noise studies. The problem manifests itself in the following phases of a noise analysis:

In the Model Validation Process

Some SHAs use the actual unrounded values that result from noise measurements and compare them with the unrounded modeled values that are generated by the Federal Highway Administration’s Traffic Noise Model (FHWA TNM). They may report the differences in tenths of a dB or round the value to the nearest whole dB number. Other SHAs round both values before calculating the difference between the values. The effects of such differences can result in different determinations regarding whether or not a noise model is considered to be validated. Noting that both noise measurement values and FHWA TNM modeling results are output in tenths of a decibel, and assuming that SHAs designate a difference between measured and modeled values of $\pm$ 3 dB as meeting their model validation requirements, the following example is presented to illustrate such variations:

Example: The measured noise level at a receiver was 64.9 dB(A). The FHWA TNM predicted the noise level associated with traffic conditions recorded during the noise measurement period to be 68.4 dB(A).

Scenario A: SHA #1 has a policy that uses unrounded values in its criteria (model validates if difference is 3.0 dB or lower) and in all noise calculations. Under its policy, the difference between the modeled noise level and the measured noise level was calculated to be 68.4 minus 64.9 = 3.5 dB. Since this value was greater than 3.0 dB, the model was not considered to be validated.

Scenario B: SHA #2 has a policy that states its criteria in whole numbers (model validates if difference is 3 dB or lower) and rounds both measured and modeled noise levels before performing validation calculations. Under its policy, the difference between the modeled noise level and the measured noise level was calculated to be 68 minus 65 = 3 dB. Since this value was equal to 3 dB, the model was considered to be validated.

Scenario C: SHA #3 has a policy that uses a rounded value of 3 dB in it model validation considerations, i.e. a difference of 3.4 dB or less is considered acceptable for validation purposes. This SHA uses the actual measured and modeled noise levels when performing validation calculations. Under its policy, the difference between the modeled noise level and the measured noise level was calculated to be 68.4 minus 64.9 = 3.5 dB. Since this value was greater than 3.4 dB, the model was not considered to be validated.

Within an SHA Noise Policy

In SHA noise policies, both absolute and relative noise abatement criteria (NAC) are most often stated as whole numbers. The most typical absolute criterion value expressed in SHA policies for external residential land uses is 66 dB(A), which represents the SHA's interpretation of approaching or exceeding the FHWA NAC of 67 dB(A). Assuming the most common rounding convention of rounding up if a value is 0.5 to 0.9 and down if a value is 0.1 to 0.4, a predicted noise level ranging from 65.5 dB(A) to 65.9 dB(A) may or may not be considered an impact, depending on an SHAs policy related to use of rounded or unrounded noise level values. For SHAs using unrounded policy and calculation numbers, a value of 65.9 dB(A) or lower would not exceed its absolute criterion value of 66.0 dB(A), and therefore would not indicate a noise impact. Conversely, for SHAs using rounded policy and calculation numbers, a value between 65.5 dB(A) and 65.9 dB(A) would be rounded to 66 dB(A), meeting its absolute criterion value of 66 dB(A), and therefore indicating a noise impact.

Each SHA's relative noise level criterion relates to the increase in design year build alternative noise levels over existing noise levels, with values stated as a single value that usually ranges from 5 to 15 dB. Assuming (for discussion purposes) an increase over existing (I.O.E.) relative criterion of 10 dB, a calculated I.O.E. value ranging from 9.5 dB(A) to 9.9 dB(A) may or may not be considered an impact, depending on an SHAs policy related to the use of rounded or unrounded I.O.E. values. For SHAs using unrounded policy and calculation numbers, a value of 9.9 dB(A) or lower would not exceed its relative criterion value of 10.0 dB, and therefore would not indicate a noise impact. Conversely, for SHAs using rounded policy and calculation numbers, a value between 9.5 dB(A) and 9.9 dB(A) would be rounded to 10 dB, meeting its absolute criterion value of 10 dB, and therefore indicating a noise impact.

During Feasibility and Reasonableness Determinations

The major implications related to the rounding of values come into play when determining noise impacts and in the evaluation of a noise barrier's feasibility and reasonableness. Under certain conditions, the rounding process employed can make a difference as to whether a receptor is determined to be impacted and/or whether a noise barrier is determined to be feasible or reasonable.

Several tables are included herein that present information related to hypothetical noise barrier that was evaluated using both rounded and unrounded noise levels. The evaluation addressed ten receivers that represented 28 receptors. The evaluation process began by considering the existing noise levels and design year build alternative noise levels from FHWA TNM output tables, presented in tenth of a dB format.

In the tables, "No Round" (or "NR") values represent the FHWA TNM noise levels expressed to the tenth of a dB, and the reported "Not Round" calculations were performed using these "unrounded" values. Noise abatement criteria were assumed to be equaled or exceeded with an absolute noise level of 66.0 dB(A) or higher, or with an I.O.E. noise level of 10.0 dB or greater.

In the tables, "With Rounding" (or "WR") values represent a rounding of the FHWA TNM noise level values, using the following rounding convention:

- Round a value between X.5 to X.9 up to the whole number (X+1).
- Round a value between X.1 to X.4 down to the whole number X."

All "With Rounding" calculations were performed using the whole number rounded values and are reported as whole decibel numbers in the "With Rounding" columns. Using these rounded values, noise abatement criteria were assumed to be equaled or exceeded with an absolute noise level of 65.5 dB(A) or higher, or with an I.O.E. noise level of 9.5 dB or greater.

A decision to round or not round values can result in a substantial difference in the number of impacted receptors. As shown in Table 1, the 24 impacted receptors calculated with rounding represent a 50 percent increase of the 16 impacted receptors calculated without rounding. For SHAs that have feasibility and/or reasonableness criteria based on having a certain number of impacted receptors being benefited, this difference could have a bearing on whether or not a barrier is determined to be feasible and/or reasonable.

A decision to round or not round values can also result in a substantial difference in the number of benefited receptors. As shown in Table 2, the 28 benefited receptors calculated with rounding represent a 22 percent increase over the 23 benefited receptors calculated without rounding. These calculations assume that any receptor that is benefited is counted equally, regardless of whether or not it is impacted.

In the calculation of total benefited receptors, some SHAs weight non-impacted receptors that are benefited differently than impacted receptors that are benefited. Assuming that an SHA gives full weight to an impacted benefited receptor and half weight to a non-impacted benefited receptor, the calculations of benefited receptor (BR) values with and without rounding are shown in Table 3. Total BR values calculated with rounding are approximately 44 percent greater than BR values calculated without rounding. The implications of such a variation can be significant, since each SHA's noise policy requires a set number or percentage of impacted receptors to be benefited in order for a noise barrier to be determined feasible and/or reasonable.

Since it has been shown that calculated BR values can be affected by the choice of rounding method, it is obvious that the SF/BR and Cost/BR values can also be affected, as shown in Table 4. Variations are also illustrated based on whether weighted or unweighted BR values were used in the cost-reasonableness evaluation process. In addition, Table 4 shows differences between average insertion loss (AIL) values based on whether rounded or unrounded values were used to compute AIL values, and also shows the resultant differences in SF/BR/AIL and Cost/BR/AIL values. Depending upon the rounding method selected and whether weighted or unweighted BR values are used, the noise barrier may not meet all reasonableness criteria. Shading indicates these conditions in the table.

Each SHA noise policy contains a reasonableness criterion related to a noise reduction design goal (NRDG). In order to comply with FHWA noise regulation (23 CFR 772), the NRDG must be between 7 and 10 dB, and SHAs must designate the number or percentage of benefited receptors that are required to meet the NRDG in order for a noise barrier to be determined to be reasonable. While the evaluation of the hypothetical noise barrier did not indicate any substantial differences in the NRDG values related to rounding methods analyzed, it is possible other project scenarios could exist where a significant difference could occur, as illustrated in Table 5.

Conclusions

While the intent of this paper is not to recommend any particular rounding method, it is, however essential that, regardless of what method is used by an SHA, the following recommendations and suggestions be considered:

Recommendation #1
Each SHA should define its convention for rounding noise level values, assuming its policy includes such rounding.

Suggested Text: "Noise level values shall be rounded based on the following convention:

1. Round a value between X.5 to X.9 up to the whole number (X+1).
2. Round a value between X.1 to X.4 down to the whole number X."

Recommendation #2
Each SHA should define its absolute NAC level as a whole number and indicate if it performs rounding.

Suggested Text: "The absolute NAC level is 66 dB(A). Any predicted total noise level equal to or exceeding 66.0 dB(A) is considered to represent a noise impact." or "The absolute NAC level is 66 dB(A). Any predicted total noise level equal to or exceeding 65.5 dB(A) is considered to represent a noise impact."

Recommendation #3
Each SHA should define its relative impact criterion value as a whole number and indicate if it performs rounding.

Suggested Text: "The relative impact criterion value is 10 dB. Any predicted increase over existing (I.O.E.) value equal to or exceeding 10.0 dB is considered to represent a noise impact." or "The relative impact criterion value is 10 dB. Any predicted increase over existing (I.O.E.) value equal to or exceeding 9.5 dB(A) is considered to represent a noise impact."

Recommendation #4

Each SHA that performs rounding should indicate at what point in the rounding process any rounding occurs and should be consistent in the application of its rounding process.

Recommendation #5

Each SHA that performs calculations based on tenth of a decibel values and then rounds the resultant values for report or table presentation purposes should include a statement similar to the following to address any "perceived inconsistencies" resulting from the rounding process:

Suggested Text: "SHA's calculation process insures that all noise levels, insertion losses, and comparisons are calculated using the actual FHWA TNM and/or noise measurement values prior to rounding. Noise values, comparisons, and insertion losses are calculated to the tenth of a decibel and then rounded for presentation purposes."

Recommendation #6
Each SHA should establish an acceptable variation associated with its model validation process.

Suggested Text: "For a noise model to be determined to be valid, the absolute difference between a measured noise level and an FHWA TNM predicted noise level shall be equal to or less than 3 dB. A model is not valid if this absolute difference exceeds 3.0 dB." or "For a noise model to be determined to be valid, the absolute difference between a measured noise level and an FHWA TNM predicted noise level shall be equal to or less than 3 dB. A model is not valid if this absolute difference exceeds 3.4 dB."

Recommendation #7
Regardless of whether or not noise level values are rounded in noise analyses and reports, it is recommended that tables and discussions related to the noise model validation and parallel barrier evaluation processes present values to the tenth of a decibel. This is because noise level comparisons in these evaluations involve small values and differences of less than a one or two dBs can be meaningful.

Recommendation #8

Regardless of whether or not an SHA applies a weighting system in determining the number of benefited receptors (BR), it should include a statement in its policy or guidance document that defines how the BR value is used in any SF/BR (or Cost/BR) calculations. The SHA should also define if and how BR values are rounded prior to calculating the SF/BR (or Cost/BR) value.

Suggested Text: The following two options are provided, depending upon how the SF value is employed in the SF/BR or Cost/BR calculation process.

Option 1: “The BR value used in the calculation of a SF/BR (or Cost/BR) value represents a weighted value. The SHA counts impacted receptors that are benefited as one benefit and non-impacted receptors that are benefited as one-half of a benefit. Therefore, for a project that has 10 impacted receptors that are benefited and 7 non-impacted receptors that are benefited, the weighted BR value is equal to 10 + 0.5*7 = 10 + 3.5 = 13.5. The SHA does (or does not) round this BR value before calculating the SF/BR (or Cost/BR) value.” The SHA should indicate how it performs (or does not perform) any rounding in the determination of the BR value. Such rounding could be performed on a receiver-by-receiver basis in a manner similar to that shown in Tables 2 and 3, or by rounding the total weighted value of “13.5 in the above equation to “14”.

Option 2: “The BR value used in the calculation of a SF/BR (or Cost/BR) value assumes that each benefited receptor is counted as one benefit, regardless of whether or not it is impacted. Therefore, for a project that has 10 impacted receptors that are benefited and 7 non-impacted receptors that are benefited, the weighted BR value is equal to 10 + 7 = 17.”

Recommendation #9
From time to time, each SHA updates and modifies its noise policy and/or noise guidance documents(s). In the process, it may modify some or all of its feasibility and/or reasonableness criteria. In doing so, it is recommended that an SHA consider the implications of its rounding method on its criteria related to the following items:

- Determining the number of impacted receptors
- Calculating a barrier’s insertion loss
- Determining the number of benefited receptors
- Any weighting of benefited receptors
- Comparison with the NRDG
- Calculating SF/BR or Cost/BR values

LIST OF TABLES

TABLE 1 Rounding Method Effect on Impacted Receptors

Barrier Information		Receiver ID and Receptors Represented		Existing Noise Level dB(A)		Design Year Build Alternative (No Barrier) Noise Level dB(A)		Increase Over Existing for Design Year Build Alternative (No Barrier) dB		Is Receptor Impacted?	
Area (SF)	Cost	ID	Number of Receptors	NR	WR	NR	WR	NR	WR	NR	WR
40,000	$990,000	1	1	57.6	58	65.2	65	7.6	7	No	No
		2	3	60.3	60	66.2	66	5.9	6	Yes	Yes
		3	5	55.8	56	65.5	66	9.7	10	No	Yes
		4	10	55.5	56	65.7	66	10.2	10	Yes	Yes
		5	1	62.0	62	63.5	64	1.5	2	No	No
		6	2	63.5	64	67.0	67	3.5	3	Yes	Yes
		7	3	63.2	63	65.6	66	2.4	3	No	Yes
		8	1	59.7	60	66.1	66	6.4	6	Yes	Yes
		9	1	60.3	60	60.5	61	0.2	1	No	No
		10	1	61.5	62	62.9	63	1.4	1	No	No
Total Number of Impacted Receptors (Indicated by Shading)										**16**	**24**
Notes: NR=No Rounding; WR=With Rounding											

TABLE 2 Rounding Method Effect on Benefited Receptors

Receiver ID and Receptors Represented		Design Year Build Alternative (No Barrier) Noise Level dB(A)		Is Receptor Impacted?		Design Year Build Alternative (With Barrier) Noise Level dB(A)		Barrier Insertion Loss dB		Number of Benefited Receptors if All Weighted Equally	
ID	**Number of Receptors**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**
1	1	65.2	65	No	No	60.4	60	4.8	5	0	1
2	3	66.2	66	Yes	Yes	60.3	60	5.9	6	3	3
3	5	65.5	66	No	Yes	60.5	61	5.0	5	5	5
4	10	65.7	66	Yes (Due to I.O.E)	Yes	59.6	60	6.1	6	10	10
5	1	63.5	64	No	No	59	59	4.5	5	0	1
6	2	67.0	67	Yes	Yes	58.4	58	8.6	9	2	2
7	3	65.6	66	No	Yes	60.7	61	4.9	5	0	3
8	1	66.1	66	Yes	Yes	54.5	55	11.6	11	1	1
9	1	60.5	61	No	No	54.5	55	6.0	6	1	1
10	1	62.9	63	No	No	53.6	54	9.3	9	1	1
Total Number of Benefited Receptors (Indicated by Shading) >>>										**23**	**28**

Notes: NR=No Rounding; WR=With Rounding

TABLE 3 Rounding Method Effect on Weighted Benefited Receptors

Receiver ID and Receptors Represented		**Is Receptor Impacted?**		**Is Receptor Benefited?**		**Impacted Receptors Benefited (Full Weighting)**		**Non-Impacted Receptors Benefited (Half Weighting)**		**Weighted Total Number of Benefited Receptors**	
ID	**Number of Receptors**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**	**NR**	**WR**
1	1	No	No	No	Yes	0	0	0	1	0	1
2	3	Yes	Yes	Yes	Yes	3	3	0	0	3	3
3	5	No	Yes	Yes	Yes	0	5	5	0	2.5	5
4	10	Yes	Yes	Yes	Yes	10	10	0	0	10	10
5	1	No	No	No	Yes	0	0	0	1	0	1
6	2	Yes	Yes	Yes	Yes	2	2	0	0	2	2
7	3	No	Yes	No	Yes	0	3	0	0	0	3
8	1	Yes	Yes	Yes	Yes	1	1	0	0	1	1
9	1	No	No	Yes	Yes	0	0	1	1	0.5	1
10	1	No	No	Yes	Yes	0	0	1	1	0.5	1
Totals						**16**	**24**	**7**	**4**	**19.5**	**28**
Notes: NR=No Rounding; WR=With Rounding											

TABLE 4 Rounding Method Effects on Cost-Reasonableness Evaluations

Assumed Criteria		
Maximum Allowable SF/BR Value	2,000	
Maximum Allowable Cost/BR Value	$50,000	
Data Related to Hypothetical Noise Barrier		
Area in Square Feet (SF)	40,000	
Cost	$990,000	
Cost-Reasonableness Calculations Assuming Unweighted BR Values	**No Rounding**	**With Rounding**
Number of Benefited Receptors	23	28
Average Insertion Loss per Benefited Receptor in dB	6.4	6.1
SF of Barrier per Benefited Receptor (SF/BR)	1,739	1,429
Cost per Benefited Receptor (Cost/BR)	$43,043	$35,357
SF of Barrier per Benefited Receptor per Average Insertion Loss (SF/BR/AIL)	272	234
Cost of Barrier per Benefited Receptor per Average Insertion Loss (SF/BR/AIL)	$6,726	$5,796
Cost-Reasonableness Calculations Assuming Weighted BR Values	**No Rounding**	**With Rounding**
Number of Benefited Receptors	19.5	26.0
Average Insertion Loss per Benefited Receptor in dB	6.5	5.8
SF of Barrier per Benefited Receptor (SF/BR)	2,051	1,538
Cost per Benefited Receptor (Cost/BR) Using Weighted BR Values	$50,769	$38,077
SF of Barrier per Benefited Receptor per Average Insertion Loss (SF/BR/AIL) Using Weighted BR Values	316	265
Cost of Barrier per Benefited Receptor per Average Insertion Loss (SF/BR/AIL)	$7,811	$6,565

TABLE 5 Rounding Method Effects on Noise Reduction Design Goal (NRDG)

Receptor	Insertion Loss in dB(A)		Number of Benefited Receptors		NRDG in dB(A)		Number of Benefited Receptors Meeting NRDG	
	No Round	**With Round**	**No Round**	**With Round**	**No Round**	**With Round**	**No Round**	**With Round**
A	6.5	7	1	1	7.0	6.5	0	1
B	7.8	8	1	1	7.0	6.5	1	1
C	8.7	9	1	1	7.0	6.5	1	1
D	5.6	6	1	1	7.0	6.5	0	0
E	6.7	7	1	1	7.0	6.5	0	1
F	6.8	7	1	1	7.0	6.5	0	1
G	6.9	7	1	1	7.0	6.5	0	1
H	5.5	6	1	1	7.0	6.5	0	0
I	4.5	5	0	1	7.0	6.5	0	0
J	3.9	4	0	0	7.0	6.5	0	0
Total Number of Benefited Receptors >			**8**	**9**	**Total Number of Benefited Receptors Meeting NRDG >**		**2**	**6**
Percent of Benefited Receptors Meeting NRDG							**25%**	**67%**
Does Noise Barrier Meet the NRDG?							**No**	**Yes**
Notes:								
NRDG Criteria: 7 dB Insertion Loss required for ≥ 50 percent of Benefited Receptors								
"No Round" Case: One-tenth of a decibel values used in all calculations; NRDG value of 7.0 dB.								
"With Round" Case: Insertion Loss values between X.5 and X.9 rounded up to the whole number (X+1); values between X.1 and X.4 rounded down to the whole number X; rounding applied to 5 dB benefit criteria and to 7 dB NRDG.								