Non-acoustical Variable Contribution to Military Blast Noise Annoyance

By Nicole Wayant

INTRODUCTION: Several factors other than noise exposure can contribute to an individual's annoyance to noise. In fact, non-acoustical variables, such as an individual's ability to habituate to noise or their personal feeling of importance towards the noise source, can have an equal or larger impact upon noise annoyance than the noise itself (Schomer et al. 2013; Guski 1999; Stallen 1999). Most of the studies that pertain to non-acoustical variables contributing to noise annoyance have focused on airplane, road, railroad, or wind turbine noise. While the results of these studies have been similar, there have been a few differences in the relationship between non-acoustical variables and noise annoyance based on the noise type. Additionally, none of the annoyance studies focused specifically on non-acoustical variable contribution to annoyance for military blast noise.

Every year the U.S. military faces training curfews, restrictions, and range-closures as a result of community annoyance to military blast noise. Indeed, training restrictions due to noise is one of the factors predicted to negatively impact military installations out to 2025 (Report to Congress on Sustainable Ranges 2013). To alleviate these issues, models that have been created to predict the percent of a community that is highly annoyed (%HA) to noise have been applied to the blast noise produced by military installations. These models take into account the noise levels the community is subjected to, but do not take into consideration the importance of *specific* non-acoustical factors, such as the frequency in which blast noise is heard or the importance of the installation to the local community. The inclusion of these non-acoustical variables could impact the predicted percentage of the community that is highly annoyed to military blast noise.

The exploration of the effect of non-acoustical variables on noise annoyance can be divided into the following two categories: attitudinal/personal variables, and situational/demographic variables. Attitudinal or personal variables can be thought of factors that result from the individual development of a person (Guski 1999). These variables can include fear of the noise source or an individual's ability to habituate to noise. In contrast, demographic variables, such as age, gender, home ownership, or dwelling type, are societal characteristics and are shared by larger groups of populations (Guski 1999). Surprisingly, there has been no, or very weak evidence that demographics contribute to noise annoyance, with the exception of wind turbine noise (Peris et al. 2012; Marquis-Favre and Premat 2005; Miedma and Vos 1999; Michard et al. 2016). Attitudinal variables, however, have been shown to strongly help explain the variance in the relationship between noise exposure and annoyance (Guski 1999; Stallen 1999; Miedma and Vos 1999; Okokon et al. 2015; Pennig and Schady 2014; Fields 1993).

The two attitudinal variables that have been most strongly associated with noise annoyance are fear of the noise source and general noise sensitivity (Guski 1999; Marquis-Favre and Premat 2005; Miedma and Vos 1999; Michard et al. 2016; Pennig and Schady 2014; Fields 1993; Wong et al. 2016). Other attitudinal contributors to noise annoyance include the duration of time between sound events, noise prevention beliefs, belief about the importance of the noise source, belief that

authorities can control the noise, capability to cope with noise, and overall general thoughts towards noise (Stallen 1999; Fields 1993; Guski 1999; Michard et al. 2016; Marquis-Favre and Premat 2005; Pennig and Schady 2014). All of these non-acoustical variables depict an individual's personal feelings towards noise. The goal of this paper is to use these non-acoustical variables, in addition to the blast noise to which a population is subjected, to predict the %HA.

The use of %HA has been accepted across the world as a standard descriptor of a community's response to noise (Schomer et al. 2013). In order to calculate this metric, the noise data must be binned into pre-determined decibel intervals. While necessary, the binning of noise data is not standardized and has the potential to misrepresent the relationship between noise and annoyance (Wayant and Nykaza 2017). There is, however, an alternative, do not bin the noise data (Wayant and Nykaza 2017; Taraldsen et al. 2016). Instead of %HA, the unbinned noise data can be used to determine the probability that a community will be highly annoyed.

Using both binned and unbinned noise data, the goal is to determine if non-acoustical variables can significantly affect the calculation of community annoyance to military blast noise. Generalized linear models (GLZMs) will be used to calculate both %HA and probability of annoyance. The results will be judged based on different goodness of fit metrics. Lastly, a recommendation will be given for which non-acoustical variables should be used in a community noise annoyance to military blast model and whether or not noise data should be binned for such a computation.

DATA AND METHODS: The data utilized in this paper was obtained from the Strategic Environmental Research and Development Program (SERDP) project WP-1546. The SERDP project investigated the metrics used to assess U.S. military blast noise, the effects of blast noise on surrounding communities, and recommended new guidelines to manage military installation noise. The SERDP project included community surveys surrounding three U.S. military installations, of these, this study focused on one, Installation B.

Following International Commission on Biological Effects of Noise (ICBEN) guidance, participants of the SERDP community survey were asked to rate their annoyance to blast noise on a five-point Likert scale considering the blast noise they had heard over a four week time period. Because of this, the noise for this study was computed into a four week, C-weighted, day-night level (CDNL_{4wk}), with one CDNL value being associated with each survey response. Additionally, based on survey responses, the SERDP dataset was divided into the following two binary groups: annoyed, and not annoyed. Individuals who rated their general annoyance to specific CDNL noise levels as 4 or 5 on the Likert scale were labeled as highly annoyed. Individuals who rated their annoyance at 3 or below were labeled as not highly annoyed. The corresponding CDNL associated with each individual's annoyance response was calculated from noise monitors located near the surveyed resident following the procedure outlined in the SERDP report. This noise-dose response data was then divided into two separate datasets, one where the CDNL data was binned into two decibel (dB) bins and another where the CDNL data was left unbinned. From these two datasets, the %HA and probability of annoyance, respectively, were predicted.

Besides noise data, the non-acoustical variables in Table 1 were also used to calculate %HA and probability of annoyance. These non-acoustical, attitudinal variables were obtained from the SERDP General Community Survey (GCS). Participants were asked to answer a variety of

questions pertaining to their attitudes towards noise and overall quality of their neighborhood. Of the 74 questions asked in the GCS, only questions relating to attitudinal variables were considered, with the exception of house type -this was included to see what, if any, affect the variable had on the final result. For the binned dataset, the mean value of each non-acoustical variable was computed for each noise bin.

Table 1. The SERDP survey questions respondents were asked, the answers from which they could choose, and the variable labels associated with each question. The answers to some of the questions were averaged to create a new variable.

Question Label	Question	Possible Answers	Variable Name
Q1	Do you think your neighborhood is quiet or noisy or about average?	1 Quiet, 2 Average, 3 Noisy	Neighborhood Noise
Q2	How often do you hear large military guns, bombs, or explosions?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very often	Frequency of Blast Noise
Q3	Which of the following best describes the type of home in which you live?	1 Single-family detached, 2 Single-family attached, 3 Multi-family home 4 Mobile home or trailer 5 Other	House Type
Q4	Were you aware that activities at "Installation B" may create noise before you first moved to your current neighborhood?	1 Yes, 2 No	Noise Awareness
Q5	How often do you recall having been awakened by noise outside your home?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very Often	Sleep Disruption
Q6	How often does the noise (in your neighborhood) startle you or make you jump?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very Often	Noise Sensitivity (Includes Q6–Q9)
Q7	How often does this noise frighten you?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very Often	
Q8	How often does the noise cause you to feel irritable or edgy?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very Often	
Q9	How often does the noise make you become tense or nervous?	1 Not at all, 2 Only occasionally, 3 Moderately often, 4 Frequently, 5 Very Often	
Q10	How would you rate the importance of "Installation B" for the economic health of your town and county?	1 Not at all important, 2 Slightly important, 3 Moderately important, 4 Very important, 5 Extremely Important	Installation Importance (Includes Q10–Q11)

Q11	How would you rate the importance of Federal funding to your local school district from "Installation B"?	1 Not at all important, 2 Slightly important, 3 Moderately important, 4 Very important, 5 Extremely Important	
Q12	I believe that people have a hard time getting used to noise.	1 Strongly disagree, 2 Moderately disagree, 3 Neither agree nor disagree, 4 Moderately agree, 5 Strongly agree	Habituation (Includes Q12–Q16)
Q13	I believe that people get used to road traffic noise.	1 Strongly disagree, 2 Moderately disagree, 3 Neither agree nor disagree, 4 Moderately agree, 5 Strongly agree	
Q14	I believe that with time most people adapt to noise.	1 Strongly disagree, 2 Moderately disagree, 3 Neither agree nor disagree, 4 Moderately agree, 5 Strongly agree	
Q15	I believe that with time I can adapt to noise.	1 Strongly disagree, 2 Moderately disagree, 3 Neither agree nor disagree, 4 Moderately agree, 5 Strongly agree	
Q16	I believe that with time I can get used to even the loudest noise.	1 Strongly disagree, 2 Moderately disagree, 3 Neither agree nor disagree, 4 Moderately agree, 5 Strongly agree	

There are a few questions whose answers were averaged together to compute a value for a non-acoustical variable. These questions are (Q6–Q9), (Q10–Q11), and (Q12–Q16). They were averaged together to calculate the non-acoustical variables Noise Sensitivity, Installation Importance, and Habituation, respectively. This was done to form a more complete picture of the variable. The variables listed in Table 1 were the most similar questions in the SERDP report as compared to the attitudinal variables identified in literature. Additionally, all variables were normalized using the standard score, where the mean variable score was subtracted from each variable data point and divided by the standard deviation.

Pearson’s correlation coefficient was used to determine if the variables listed in Table 1 were significantly correlated to community annoyance to military blast noise. The correlation was evaluated at $\alpha = 0.05$. If $p > 0.05$ then the relationship between the non-acoustical variable and annoyance was considered insignificant. Insignificant variables were not used to predict %HA or probability of annoyance.

Once the non-acoustical variables that were significantly correlated to annoyance were determined, the non-acoustical variables, along with the noise metric CDNL, were normalized and plugged into a least absolute shrinkage and selection operator (LASSO) regularization for GLzM. LASSO is a regularization technique that helps with model variable selection, giving coefficients of 0 to independent variables that do not contribute to the predication of the dependent variable. The LASSO technique was used to help estimate the coefficients of the GLzM. LASSO was

performed with 100 different λ values for each GLzM, where λ is the varying nonnegative regularization parameter.

GLZMs were used to predict the %HA and probability of high annoyance for the binned and unbinned datasets. GLZMs is a special class of nonlinear models that uses linear methods to model non-Gaussian data. The dependent variable can have any exponential distribution such as Gaussian, binomial, Poisson, gamma, or inverse Gaussian. This is accomplished through the use of a link function, linearly transforming the data. In practice, the link function is specific to the distribution of the dependent variable, in this case annoyance. Since the basis of the dependent variable is highly annoyed, or not highly annoyed, our distribution is binomial and our corresponding link function is logit (Wilson et al. 2013).

Goodness of fit was determined in several ways. The first was by the use of deviance. Deviance is a general quality of fit statistic which is often used to determine which GLzM best fits the available data. Models with a lower deviance are considered to better represent the data. The λ GLzM associated with the smallest deviance was used to test the predictive power of the non-acoustical variables.

Additionally, for the noise binned dataset, the root mean square error (RMSE) was used to determine the difference between observed and predicted %HA values. For the models developed from the unbinned data, accuracy and precision metrics were calculated. Accuracy measures the overall proportion of correct classifications, whereas precision measures the portion of persons correctly classified as highly annoyed over the number of all persons classified as highly annoyed. To use these metrics, the predicted probability of annoyance was rounded to either 0 (not annoyed) or 1 (annoyed).

Lastly, cross-validation was performed on all of the models. The models were trained on a random 70% of the data and tested on the remaining 30%. This was done a total of 30 times. An average across all runs was computed for the following: coefficients, RMSE, accuracy, and precision. A cross-validation of GLzM for only CDNL and annoyance was also run. A student t-test was run between the non-acoustical variable models' and the CDNL only models' goodness of fit metrics to see if the two types of models were statistically different.

RESULTS: The results of the Pearson's correlation analysis are listed in Tables 2 and 3. Interestingly, the significance of the relationship between the non-acoustical variables and annoyance is not the same for the binned and unbinned datasets. For the binned dataset, the relationship between Noise Awareness and %HA was not possible to calculate, due to the Noise Awareness value being the same in every 2 dB bin. The variables that were significantly correlated to %HA were Frequency of Blast Noise, House Type, Sleep Disruption, Habituation, and Installation Importance, with the Frequency of Blast Noise having the highest coefficient. It is odd that House Type is so highly correlated with %HA as the literature shows this variable does not contribute to annoyance. In contrast, all of the unbinned non-acoustical variables were significantly related to annoyance except for House Type.

Table 2. Correlation coefficients and p-values of non-acoustical variables and probability of annoyance.		
Non-acoustical Variable	Coefficient	P-Value
Neighborhood Noise	0.085	0.72
Frequency of blast noise	0.74	~0
House Type	-0.47	0.03
Noise Awareness	NAN	NAN
Sleep Disruption	0.51	0.0171
Noise Sensitivity	0.23	0.32
Habituation	-0.46	0.04
Installation Importance	-0.61	~0

Table 3. Correlation coefficients and p-values of non-acoustical variables and %HA.		
Non-acoustical Variable	Coefficient	P-Value
Neighborhood Noise	0.27	~0
Frequency of blast noise	0.65	~0
House Type	0.04	0.46
Noise Awareness	-0.23	~0
Sleep Disruption	0.22	~0
Noise Sensitivity	0.41	~0
Habituation	-0.32	~0
Installation Importance	-0.17	~0

The significantly correlated non-acoustical variables, in addition to CDNL, were inputted into to a LASSO GLzM. For each LASSO GLzM, the λ model with the lowest deviance was selected. The mean coefficients for each independent variable across the 30 cross-validation runs is listed in Tables 4 and 5. On average the RMSE for the binned dataset was 14.11 %HA. The unbinned dataset had an average accuracy and precision score of 86.16% and 83.41%, respectively.

Table 4. Average GLzM coefficients across 30 cross-validation runs for each significantly correlated non-acoustical variable correlated to %HA.	
Variable	Mean Coefficient
Frequency of Blast Noise	0.03
House Type	~0
Sleep Disruption	~0
Habituation	-0.13
Installation Importance	-0.03
CDNL	~0

Table 5. Average GLzM coefficients across 30 cross-validation runs for each significantly correlated non-acoustical variable correlated to probability of annoyance.

Variable	Mean Coefficient
Neighborhood Noise	0.14
Frequency of Blast Noise	0.34
Noise Awareness	-0.27
Sleep Disruption	-0.05
Noise Sensitivity	0.63
Habituation	-0.31
Installation Importance	-0.40
CDNL	0.08

It is interesting to note that while the house type was deemed significantly correlated to the %HA, the variable itself has a very small correlation coefficient and GLzM coefficient. Indeed, the average GLzM coefficient is approximately 0. This is in keeping with other noise annoyance research findings, that the demographic variable housing type does not affect one's annoyance to noise (Marquis-Favre and Premat 2005). Possible explanations for this could be the large size of the dataset.

The non-acoustical variables that were used to predict %HA have in general much smaller coefficients than their unbinned counterparts. Habituation had the highest coefficient of -0.13. All other coefficients are close to, or are approximately 0. With the exception of Sleep Disruption and Neighborhood Noise, the non-acoustical coefficients used to predict probability of annoyance are much larger.

The largest contributor to probability of military blast noise annoyance is Noise Sensitivity. Within the literature, this was one of the non-acoustical variables that was shown to greatly affect annoyance to other noise sources. Additionally, there was a negative relationship between the probability of annoyance and the following variables: Installation Importance, Habituation, and Noise Awareness. This means that the more important the installation was to an individual, or the more they felt they were able to habituate to noise, or were knowledgeable that the noise occurred, the less likely they were to be annoyed. Surprisingly, the GLzM coefficients for unbinned Sleep Disruption were relatively small, as were the CDNL coefficients

Lastly, when the mean 30 cross-validation goodness of fit metrics RMSE, accuracy, and precision are compared to the goodness of fit metrics generated from GLzM models developed with only CDNL as an independent variable, the metric datasets were found to be statistically different from each other at the $\alpha = 0.05$. This means that at a 5% level of significance that non-acoustical variables do contribute to the prediction of %HA and probability of annoyance.

DISCUSSION AND SUMMARY: The correlation coefficients between non-acoustical variables and annoyance differed greatly for both %HA and probability of annoyance. This could be due to

the binning of the noise data that is needed to calculate the %HA. As stated in Wayant and Nykaza 2017, the binning of data has the potential to introduce errors. When the data is not binned, the correlation between non-acoustical variables and annoyance is more in line with past research results. Additionally, the GLzM coefficients used to predict %HA are in general rather small and the RMSE high. Because of this, it is recommended to not bin the noise data and to instead try to predict the probability of annoyance for the community.

The GLzM coefficients that contributed the most to the predication of probability of annoyance are as follows: Neighborhood Noise, Frequency of Blast Noise, Noise Awareness, Noise Sensitivity, Habituation, and Installation Importance, with Noise Sensitivity having the largest coefficient. Sleep Disruption and CDNL both had relatively small coefficients. The demographic variable House Type was not significantly correlated with annoyance. In order to predict probability of annoyance, it is recommended to use the non-acoustical variables Noise Sensitivity, Neighborhood Noise, Frequency of Blast Noise, Noise Awareness, Habituation, and Installation Importance.

What was perhaps the most interesting finding of the research was the small CDNL GLzM coefficients. With the exception of two non-acoustical variables, CDNL had the smallest GLzM coefficient for both datasets. For the binned dataset, the coefficient was approximately 0, and for the unbinned dataset, the coefficient was 0.08. Since all of the independent variables were normalized before being inputted in the GLzM, these coefficients seem especially low and raises the question of whether or not noise is the largest contributor to military blast noise annoyance. More research is needed to see if noise itself plays a significant role in annoyance to military blast noise.

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