

Problem Set 8

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CEE 260/MIE 273: Probability & Statistics in Civil Engineering

11.19.2025

*Due Friday, November 26, 2025 at 11:59 PM as PDF uploaded on Canvas. **Show as much work as possible in order to get FULL credit.** There are 10 problems with a total of 63 points available.*

1 Project Overview

Objective: Investigate the relationship between barrier material properties and sound attenuation, then apply linear regression analysis to model this relationship.

Engineering Context: Sound attenuation is critical in environmental engineering (highway noise barriers), civil engineering (building acoustics), and mechanical engineering (equipment noise reduction). Understanding how materials block sound allows engineers to design effective noise control solutions.

What You'll Learn:

- How different materials attenuate sound
- The relationship between material thickness/density and sound reduction
- Linear regression modeling of experimental data
- Real-world applications in noise control engineering

2 Background: Sound and Decibels

Sound Level (dB): Logarithmic scale measuring sound pressure. Every 10 dB increase represents a doubling in perceived loudness.

Sound Attenuation: The reduction in sound intensity as it passes through a material or barrier.

Key Principle — Mass Law: Sound transmission loss increases with material mass per unit area. Heavier, denser materials generally block more sound.

Sound Reduction (dB) = Baseline Level (dB) - Measured Level (dB)

Example: 85 dB baseline - 70 dB with material = 15 dB reduction

3 Materials & Equipment

Provided by Instructor:

- Cardboard test box
- Bluetooth speaker
- Various barrier materials
- Tape and clips

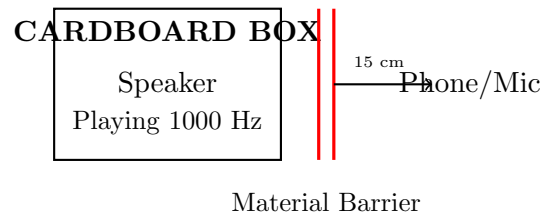
Bring Your Own:

- Smartphone with decibel meter app
- Ruler or calipers
- Calculator
- Laptop for data analysis

Important: Download a free decibel meter app BEFORE lab:

- **iOS:** “Decibel X” or “NIOSH Sound Level Meter”
- **Android:** “Sound Meter” or “Decibel X”

4 Experimental Setup



Setup Steps:

1. Place speaker inside cardboard box, centered
2. Install test material over opening (secure all edges with tape)
3. Position phone microphone 15 cm from material surface
4. Start tone generator app (1000 Hz, constant volume)
5. Calibrate: wait 10 seconds for sound stabilization

5 Experimental Procedure

Part 1: Baseline Measurement

1. With NO material installed (open box), measure sound level
2. Take 3 measurements, record all values
3. Calculate average — this is your **baseline**
4. DO NOT change speaker volume for rest of experiment!

Part 2: Material Testing

1. Select first test material and measure its thickness with ruler/calipers
2. Install material, ensuring edges are sealed with tape
3. Wait 5 seconds for sound to stabilize
4. Take 3 sound level measurements
5. Calculate average and sound reduction
6. Remove material and repeat for next sample
7. Test ALL materials in your assigned set

Critical Controls:

- Keep microphone at same distance (15 cm) for ALL tests
 - Keep phone orientation consistent
 - Seal material edges completely (no air gaps!)
 - Don't change speaker volume between tests
 - Test in quiet environment (minimize background noise)
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6 Data Collection Sheet

Test Conditions:

Baseline Sound Level (no material): _____ dB

Test Frequency: 1000 Hz

Microphone Distance: 15 cm

Background Noise Level: _____ dB

Material	Thickness (mm)	Mass/Area (g/cm ²)*	Trial 1 (dB)	Trial 2 (dB)	Trial 3 (dB)	Average
Baseline (No Material)	0	0				

**Mass per area can be calculated if you weigh a known area of material, or estimated from material density tables*

7 Data Analysis Requirements

1. Create Scatter Plot

Plot **Material Thickness (mm)** on x-axis vs. **Sound Reduction (dB)** on y-axis

- Include all data points from your experiment
- Label axes clearly with units
- Add descriptive title

2. Linear Regression Analysis

Calculate the least-squares regression line: $y = mx + b$

Where:

- y = Sound Reduction (dB)
- x = Material Thickness (mm)
- m = slope (dB reduction per mm)
- b = y-intercept (baseline)

Report the following: • Regression equation: $y = \text{_____} x + \text{_____}$ • Slope (m): _____
 dB/mm • Y-intercept (b): _____ dB • Correlation coefficient (r): _____ • Coefficient
 of determination (R²): _____

3. Plot Regression Line

Add your regression line to the scatter plot created in step 1

4. Residual Analysis

Create a residual plot (residuals vs. predicted values) to check if linear model is appropriate

8 Discussion Questions

Statistical Analysis (Answer with complete sentences)

1. Interpret the slope of your regression line. What does it tell you about the relationship between thickness and sound reduction?
2. What is your R^2 value? What percentage of the variation in sound reduction is explained by material thickness?
3. Based on your residual plot, is a linear model appropriate for this data? Explain why or why not.
4. Use your regression equation to predict the sound reduction for a 10 mm thick barrier. Is this an interpolation or extrapolation?

Material Performance

5. Which material provided the best sound reduction per unit thickness? Calculate dB reduction per mm for each material.
 6. Did denser materials perform better than lighter materials of the same thickness? Support your answer with data.
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Engineering Applications

7. A residential building is exposed to 75 dB of highway noise. Building codes require interior noise levels below 45 dB. Using your best-performing material, what thickness would be required? Show your calculation.

8. Research typical costs for your tested materials (\$/sq ft). Which material provides the best sound reduction per dollar?

9. In real buildings, walls often consist of multiple layers with air gaps (e.g., drywall + air gap + insulation + drywall). Why might this design perform better than a single thick layer? (Research “decoupling” and “resonance”)

10. Low-frequency sounds (bass, truck engines) are much harder to block than high-frequency sounds. How might this affect your material recommendations for highway noise barriers vs. HVAC noise control?

9 Sources of Error

Identify at least THREE sources of experimental error in your study and explain how each could affect your results:

Error 1:

Error 2:

Error 3:

10 Engineering Design Recommendation

Design Scenario: You are designing a noise barrier for a new highway expansion project. The barrier must reduce traffic noise from 80 dB to 60 dB at nearby homes. Based on your experimental findings, propose a barrier design that considers:

- Material selection (type and thickness)
- Estimated cost per linear foot of barrier
- Structural considerations (weight, wind resistance)
- Maintenance requirements
- Aesthetics and community acceptance

Your Recommendation:

Justification (use data from your experiment):

11 Report Requirements

Due Date: _____

Deliverables:

1. **Completed data sheet** with all measurements
 2. **Scatter plot** with regression line
 3. **Residual plot**
 4. **Regression analysis** (equation, R^2 , interpretation)
 5. **Answers to all discussion questions**
 6. **Engineering design recommendation**
 7. **Sources of error analysis**
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Grading Criteria:

- Data collection completeness and accuracy (20%)
- Statistical analysis correctness (25%)
- Quality of graphs and visualizations (15%)
- Depth of discussion and engineering application (25%)
- Design recommendation and justification (15%)

12 Additional Resources

Recommended Reading:

- STC (Sound Transmission Class) ratings and building codes
- Mass Law for sound transmission: $TL \approx 20 \log(f \times m) - 42$
- OSHA noise exposure standards for workplace safety
- Highway noise barrier design guidelines (FHWA)

Software for Analysis:

- Excel, Google Sheets (built-in regression functions)
- Python (scipy.stats, matplotlib)
- R (lm function)
- Any statistical software package