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Research Articles

Test method for evaluating the NIOSH Noise Mapper application in a hemi-anechoic chamber

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The Noise Mapper Application currently under development by the National Institute for Occupational Safety and Health (NIOSH) can be used to identify areas in the workplace where workers may be exposed to hazardous noise. The application is intended to empower workers to measure sound levels in their workplace, make informed decisions about noise exposure, and prevent occupational hearing loss.

To evaluate the maps generated by the app, a single sound source or multiple sources were used to generate steady state sound fields within the NIOSH Hemi-anechoic Chamber (HAC). A sound level meter (Larson Davis, Model LxT1) was used to measure A-weighed equivalent continuous sound levels on a grid with a spacing of 1.5 m (5 ft). The NIOSH Noise Mapper Application was then used to generate sound level contour plots with a grid spacing of 3.0 m (10 ft). The accuracy of the map was evaluated by comparing the predicted sound levels with the measured sound levels. The results show the app can estimate the sound levels to within 1.5 dB(A) of the measured values when half of the measured points were used to generate the contour plot.

The test method used to evaluate the NIOSH Noise Mapper Application and the results of the comparison will be discussed in this paper.

1. INTRODUCTION

Noise-induced hearing loss is a serious and common occupational health hazard with considerable social and physiological impact.[1] Exposure to intense noise can damage the inner ear and cause permanent hearing loss. Unfortunately, increased activities in the mining industry have been accompanied by worsening noise pollution for the workers. Commonly, noise dosimeters and sound level meters (SLMs) are used to assess worker noise exposure and equipment sound levels. However, a convenient and economic method for the assessment of a worker's noise environment is essential so that the workers can take proper action regarding hearing loss prevention. Several researchers have used smartphones with sound-monitoring applications to evaluate workers' noise environments. Ibekwe et al. compared the accuracy of mobile smartphones equipped with the Android app to a standard sound level meter (SLM) in measuring noise levels.[2] Sun et al. tested the NIOSH Sound Level Meter app for accuracy in measuring sound levels in mining environments.[3] Celestina et al. tested smartphones with the NoiSee app and concluded that smartphones equipped with appropriate apps can achieve compliance with IEC and ANSI standards.[4] Hong et al. claimed that there are significant variations in mean sound level values among Android smartphones when using three SLM applications. Similarly, various mean sound level values can arise across different SLM applications on Android devices.[5]

The NIOSH Noise Mapper Application, which has both Android version and iOS version, generates sound level contour maps of a workplace, graphically revealing work areas where the sound levels are safe and those which are hazardous to hearing. The maps assist in determining locations for placing noise hazard signage, locating personal protective equipment, and performing site-specific hazard training. In this paper, the NIOSH Noise Mapper Application's accuracy for predicting the sound level at sound sources (local maximums) was evaluated and validated in the laboratory with an SLM.

2. METHODOLOGY

The test method covers the measurement of sound in the NIOSH Hemi-anechoic Chamber (HAC) for the purpose of evaluating the NIOSH Noise Mapper Application. Procedures for measuring the sound field produced by a single or multiple sound sources to evaluate the app are described. It is noteworthy that this test method itself does not address safety concerns, if any, associated with using the app.

A single sound source or multiple sources were used to generate sound fields within the NIOSH HAC. The sound source(s) was (were) activated and the resulting sound field was allowed to reach a steady state. Overall and one-third-octave band A-weighted sound levels within the room were

Fig. 1. The 16.6 m x 9.9 m x 6.4 m NIOSH Hemi-anechoic Chamber (HAC).

calculated and recorded with a sound level meter. The operator stood away from the SLM and the smartphones to minimize the interference during recording. Only the SLM results were then used to map the sound field as a baseline reference for comparison with results obtained using the NIOSH Sound Mapper application and respective data collection device (i.e., smartphone) to evaluate the device and/or application for measuring sound and/or generating sound maps. Both the Android version and iOS version use the same algorithm to generate the noise heatmap. In this paper, the sound pressure level at each survey point was measured using the sound level meter (NOT the app). The data was then entered into the app (either iOS or Android) to generate noise heatmap. The app estimated value was then compared with measured value at some grid points to check the app's predication accuracy.

3. TEST SETUP

The test was conducted in the NIOSH HAC as described below.

3.1. The NIOSH Hemi-anechoic Chamber (HAC)

The HAC is constructed of a concrete floor and masonry block walls (Figure 1). The walls and ceiling are treated with Eckel Industries SuperSoft® panels. The HAC has a cut-off frequency of 100 Hz. The HAC is used primarily for noise source identification on mining equipment. The inside room dimensions are 16.6 m long by 9.9 m wide by 6.4 m high with an approximate volume of 1,000 m^3.

3.2. Instrumentation and Software

3.2.1. Sound Sources

Two reference sound sources, a Bruel & Kjaer 4204 Reference Sound Source (50 Hz to 20 kHz) and an Acculab RSS 101 Reference sound source (100 Hz to 8 kHz), were used to generate broad band sounds with uniform frequency content (Figure 2). Four JBL EON710-NA speakers (65 Hz to 20 kHz) with built-in amplifiers were used to generate pink noise or machine sounds from a roof bolter, continuous miner, air compressor, or haul truck.

3.2.2. Audio Signal Generators

Four (4) Minirator MR-PRO/MR2 audio signal generators (Figure 2) were used to drive the JBL speakers with pink noise or noise produced by a continuous miner, roof bolter, air compressor, or haul truck.

3.2.3. Sound Level Meter

A Larson Davis LxT1 Type/Class 1 sound level meter (SLM) was used as the reference device (Figure 2). This SLM meets ANSI/IEC standards for Type 1 sound level meters, ANSI S1.4-2014 specification for Type 1 sound level meters, and IEC 61672-1:2013 for Type 1 sound level meters. The calibration curve is shown in Fig. 3.

3.2.4. The NIOSH Noise Mapper Application

Developed by NIOSH, the Noise Mapper Application is an iOS- and/or Android-based application that can generate a sound contour map (noise map) of a work area (Fig. 2). With the app, workers can create a map and conduct a noise survey of a work area using a cell phone's built-in microphone or an external sound device such as an SLM. The generated noise map can help workers to locate noise-generating machinery in the work area. The newest version of the app—Build 1.0.32, 12/19/2023, internal evaluation—added the ability to timestamp exported sound level readings. The app also has the capability of entering wall length, displaying missing data points, and exporting data to show missing data points based on cubic spline and BlockLLS interpolation algorithms. The cubic spline interpolation is a special case for spline interpolation which gives an interpolating polynomial that is smoother and has smaller error than some other interpolating polynomials such as Lagrange polynomial and Newton polynomial. The BlockLLS is one of the solvers for bicubic spline interpolation (the bicubic spline interpolation is an extension of cubic spline interpolation on a two-dimensional grid). The app can interpolate the sound levels between measured data points. The app's new features give the capability of interpolating sound levels at places having limited or no access, so the workers can take proper action regarding hearing loss.

3.3. Test Procedure

A 1.5 m x 1.5 m (5 ft x 5 ft) grid was generated in the hemi-anechoic chamber (Fig. 4) based on the size of the

Fig. 2. Instruments used in the test.

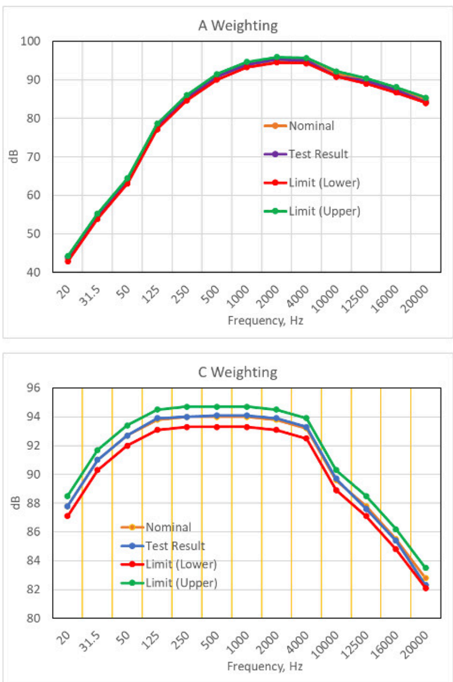

Fig. 3. Sound level meter calibration curve (by NovaStar Solutions).

room. A Larson Davis LxT1 SLM was used to measure the A-weighted sound level at all 65 points.

For reference, the HAC was divided into four quadrants, Q1, Q2, Q3, and Q4. The center of the HAC was marked as C, and the centers of each quadrant were marked as Q1C, Q2C, Q3C, and Q4C, respectively. The sound sources were placed at point C, or Q1C through Q4C, depending on the test, as shown in Fig. 5.

Different sound sources and sound levels were used for the measurements to represent the complex sound fields in mining environments. Table 1 lists all the scenarios for the testing. Four scenarios were used. For Scenario 1, the sound source was a B&K Reference Sound Source (RSS) which was located at C. The B&K RSS was powered by a variable transformer to adjust the voltage supplied to the RSS during the test. The variable transformer was used to adjust the RSS fan speed so that the sound level 2 m from the RSS was 85 dB(A). For Scenario 2, the sound sources were the B&K RSS and an AccuLab RSS. The B&K RSS was located at Q1C, while the AccuLab RSS was located at Q3C. The speed of each RSS was set to a value so that the sound level 2 m from each RSS was 90 dB(A) while the other RSS was off. Four JBL EON710-NA loudspeakers were placed inward at Q1C through Q4C in Scenario 3. Two cases were tested in Scenario 3. For Scenario 3 Case 1, each of the four speakers were driven with pink noise from four separate Minirator MR-PRO/MR2 audio signal generators to generate a sound level of 80 dB(A) at 2 m from each speaker with the other speakers off. For Scenario 3 Case 2, the speakers at Q1C, Q2C, Q3C, and Q4C played pink noise at 80, 85, 90, and 95 dB(A), respectively, measured at 2 m from each speaker with the other speakers off. In Scenario 4, the speakers at Q1C, Q2C, Q3C, and Q4C were placed inward and played continuous miner noise at 88 dB(A), roof bolter noise at 95 dB(A), air compressor noise at 97 dB(A), and haul truck noise at 90 dB(A), respectively, measured at 2 m from each speaker with the other speakers off.

One dosimeter (Larson Davis Spartan 730IS) was positioned 2 m in front of each sound source at a height of 1.5 m. The A-weighted sound level for each measurement point and test condition were recorded and evaluated with the app when the sound source(s) were active, and the HAC

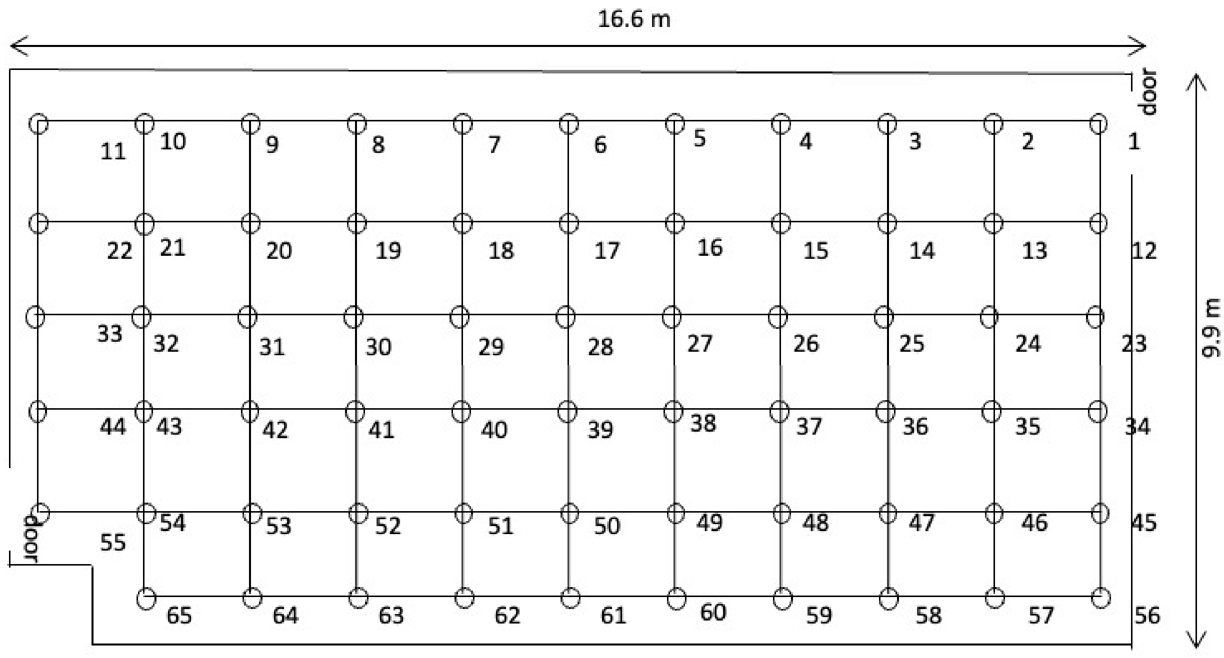

Fig. 4. The 1.5 m x 1.5 m grid in the hemi-anechoic chamber.

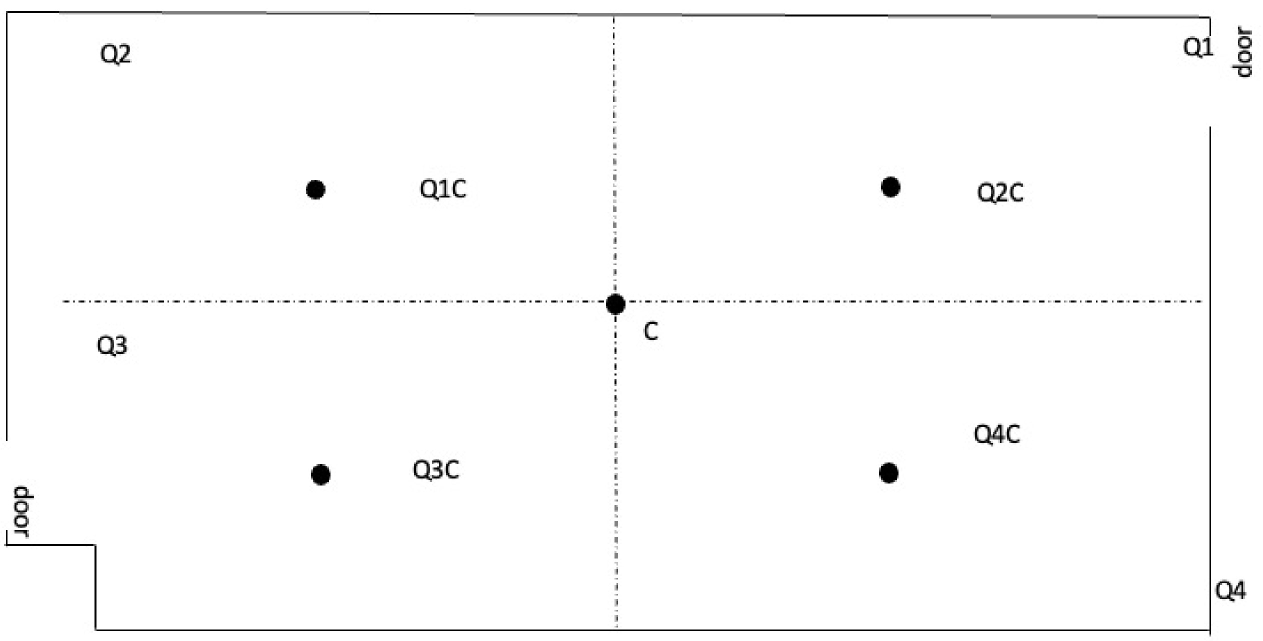

Fig. 5. Locations of the sound source(s).

was vacant of personnel (except the recording person). The measurement duration for both the SLM and Noise Mapper Application measurements was 30 seconds. The analyses included the overall and one-third-octave band A-weighted equivalent continuous sound levels in the frequency range from 20 Hz to 12.5 kHz. The SLM was mounted on a tripod at the height of 1.5 m pointing up at approximately 70°. The SLM was calibrated before and after each experiment using a Larson Davis model Cal 150 acoustic calibrator.

4. RESULTS

The A-weighted equivalent continuous sound level (L_{Aeq}) was recorded using the Larson Davis LxT1 SLM at each grid point within the room (65 measurement points total) for each of the four scenarios as described above. The app then generated a 2D contour map for the sound levels within the room based on the measurement data for each scenario and each case.

Table 1. Testing scenario for different sound sources

SCENARIO	Sources	Location(S)	Sound level(s)
Scenario 1	1 B&K RSS	C	85 dB(A)
Scenario 2	1 B&K RSS 1 Acculab RSS	Q1C Q3C	90 dB(A) 90 dB(A)
Scenario 3	4 JBL Speakers	Q1C Q2C Q3C Q4C	All pink noise. Case 1: all 80 dB(A) Case 2: 80, 85, 90, 95 dB(A) for each speaker at Q1C through Q4C, respectively
Scenario 4	4 JBL Speakers	Q1C Q2C Q3C Q4C	continuous miner noise, 88 dB(A) roof bolter noise, 95 dB(A) air compressor noise, 97 dB(A) haul truck, 90 dB(A)

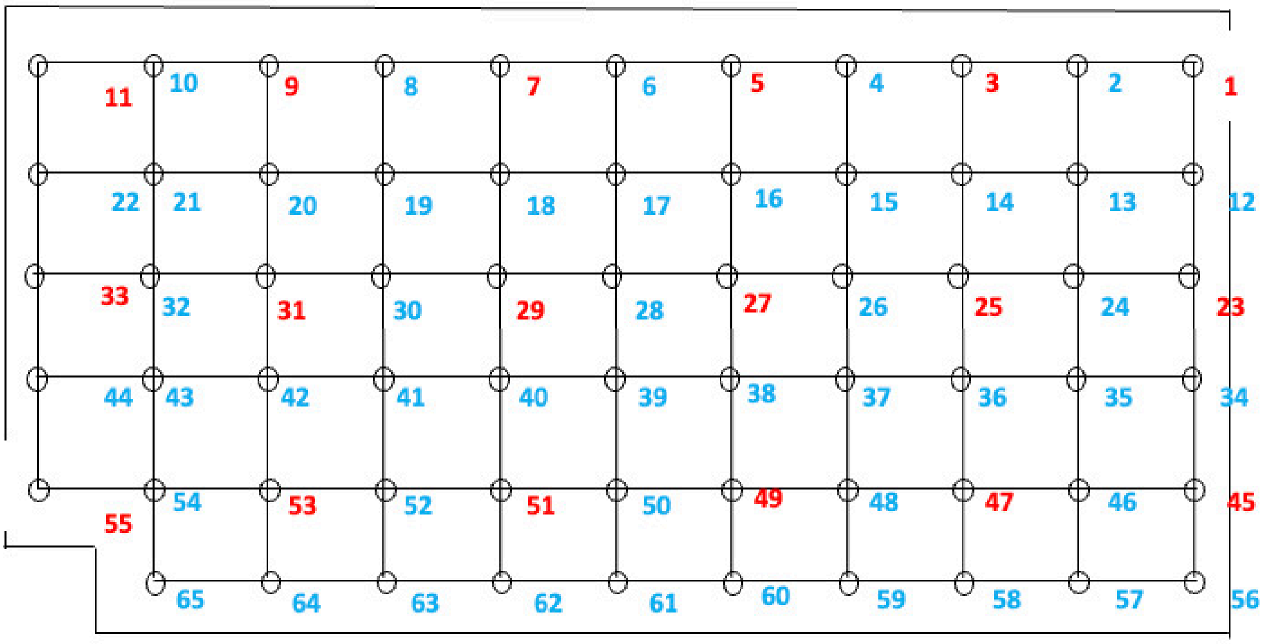

Fig. 6. A 3.0 m x 3.0 m grid (labeled in red) was used for the app to generate the sound level contour map. The sound levels at the missing points (labeled in blue) calculated by the app were then compared with the measured data at the points that were excluded.

To validate the accuracy of the sound levels estimated by the app, only part of the measurements was used to generate additional contour maps. The app was used to generate sound level contour plots with a grid spacing of 3.0 m (10 ft) (Fig. 6). The sound levels at the missing points calculated by the app were then compared with the measured data at the excluded points.

As an example, Fig. 7 shows the sound level contour maps based on different grid spacing for Scenario 4. There is no doubt that the smaller grid size results in the app generating a more accurate sound level contour plot in the room. However, it is impractical to survey at a very small grid size, especially for a large area. The user needs to balance the accuracy and the workload while using the app to conduct a survey. The box plot of the measured sound level at all the survey points and the estimated sound level at the excluded points using partial of the measurements for all test scenarios is shown in Fig. 8. *Table 2* lists the difference between the app's estimation and the SLM measurement at missing points for all scenarios. The data show that the app can estimate the sound levels to within an average of 1.5 dB(A) of the measured values.

To further investigate the app's capability to estimate the sound level at the local maximum (the sound source)—the measurement points at or close to the sound source(s)—was (were) excluded from the app input, and the app was used to calculate the sound level(s) at the missing point(s) by interpolating the adjacent values and to generate sound level contour map. Again, the sound levels at the missing points calculated by the app were then compared with the measured data at the excluded points.

For Scenario 1, the sound source was located at Q1C (as shown in Fig. 5). The local maximum was at grid point 28 as shown in Fig. 4. The app-generated sound level contour

Table 2. The difference between sound levels estimated by the app and sound levels measured with an SLM at the excluded points.

Difference, L_{Aeq}, dB(A)	Scenario 1	Scenario 2	Scenario 3		Scenario 4
			Case 1	Case 2	
mean	1.5	1.3	1.2	1.3	1.5
maximum	2.8	3.6	3.5	3.5	4.3
standard deviation	0.7	0.8	0.9	0.8	1.0

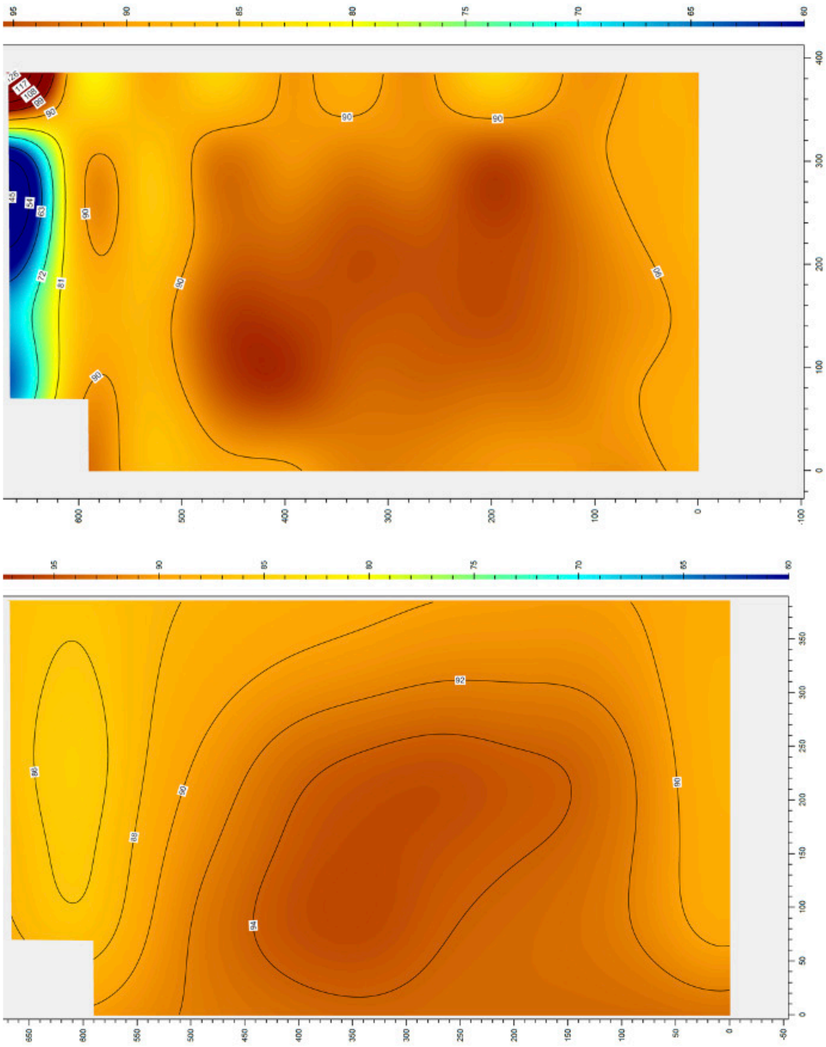

Fig. 7. Sound level contour map based on 5 ft x 5 ft grid (top) and 10 ft x 10 ft grid (bottom) measurements for Scenario 4.

map based on the measurements at all the grid points except point 28 was compared with the map that was based on the measurements at all the grids. For Scenario 2, the sound sources were located at Q1C and Q3C (as shown in Fig. 5). The local maximums were at grid point 19 and 53 as shown Fig. 4. The app-generated noise contour map based on the measurements at all the grid points except point 19 and 53 was compared with the map that was based on the measurements at all the grids. For Scenario 3, the sound sources were located at Q1C though Q4C (as shown in Fig. 5). The local maximums were at grid points 15, 19, 48, and 52 as shown Fig. 4. The app generated noise contour map based on the measurements at all the grid points except point 15, 19, 48, and 52 was compared with the map based on the measurements at all the grids. For Scenario 4, the sound sources were located at Q1C through Q4C (as shown in Fig. 5). The local maximums were at grid points 15, 19, 48, and 52 as shown Fig. 4. The app-generated noise contour map based on the measurements at all the grid points except points 15, 19, 48, and 52 was compared with the map based on the measurements at all the grids, as shown in Fig. 9. The figure shows that the app gives close sound level contour plots while only few points are missing. *Table 3* lists the difference between the measurement value and the es-

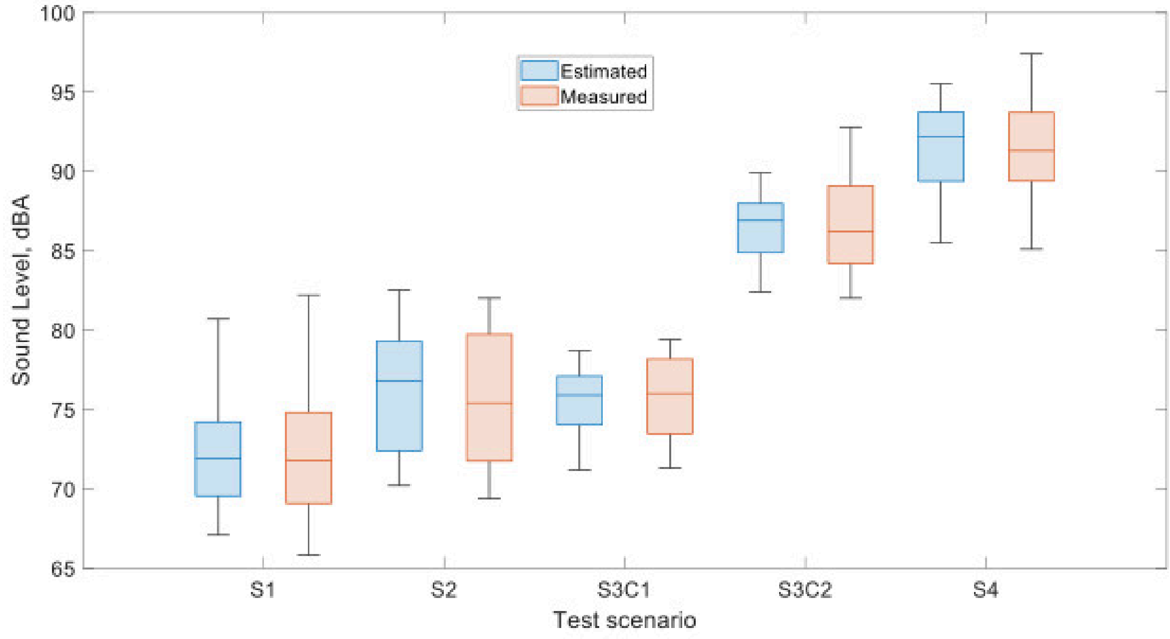

Fig. 8. The box plot of the measured sound level at all the survey points (pink) and the estimated sound level at the excluded points based on partial of the measurements (blue).

timated value at the local maximum for all the scenarios. The average difference was -1.0 dB with a standard deviation of 1.1 dB.

5. DISCUSSION AND CONCLUSIONS

The findings of this study demonstrate the effectiveness of the NIOSH Noise Mapper Application in accurately interpolating sound levels in laboratory environments. By utilizing a controlled setting with single or multiple sound sources in a hemi-anechoic chamber, the app was evaluated for its ability to generate sound level contour maps that reflect measured sound levels. The implications of these findings are significant for occupational safety and health professionals that need a simple tool to visualize noisy areas in large industrial work areas. By empowering workers to measure sound levels and visualize noisy areas in their workplaces through sound level contour maps, the app enables informed decision-making to reduce occupational hearing loss. Additionally, the ability to accurately estimate sound levels can aid in determining appropriate locations for noise hazard signage and personal protective equipment placement. Furthermore, this information can be used when conducting site-specific hazard training.

One observation based on *Table 3* is that the app's estimation tends to be lower than the measurement. Overall, the results show the app can estimate the sound levels to within 1.5 dB(A) (with a standard deviation of 1.0 dB(A) or less) of the measured values while doubling the grid spacing. Obviously, the app's estimation error (compared with the SLM measured value) is caused by the app when it interpolates the measured data. When only a few points are excluded, the app's estimation can closely match measured values, with an average difference of 1.0 dB(A) and a standard deviation of 1.1 dB(A) at the local maximum. This level of accuracy suggests that the Noise Mapper Application can be a valuable tool for identifying areas of potential noise hazard in the workplace.

The objective of the app's new feature is to estimate sound levels at locations between survey points. For example, assume there is a sound source at the center of four survey points and that the source has no access to it. Consider that location as p5. If the app predicts the sound level at p5 above (rather than below) the values at the four adjacent survey points based on the surrounding surveys, the predicted value will be closer to reality because p5 is the sound source location and the sound level there should have the highest value in this local area (local maximum). So, even if the user cannot take a measurement at p5, the app can still give a reasonable estimate to take proper action regarding hearing loss prevention. Two factors should be considered when choosing the grid size for a large area to be surveyed: the accuracy and the total measurement time. The test results presented in this paper could give the user an idea of how well the app can predict missing points and how to balance those two factors when creating contour maps of large areas in the field.

In conclusion, the NIOSH Noise Mapper Application shows promise as a tool for assessing noise exposure and preventing occupational hearing loss. Further validation studies in diverse workplace settings with a wide variety of sound fields and user evaluations are warranted to fully evaluate the app's effectiveness and usability in practical occupational safety and health applications.

Table 3. The app's predication at local maximum compared with SLM measurement.

	Missing point(s) (local maximum)	L_{Aeq} at missing point (local maximum), SLM measurement, dB	L_{Aeq} at missing point (local maximum), app predication, dB	Difference, dB
Scenario 1	28	82.2	81.8	-0.4
Scenario 2	19, 53	82.7	81.3	-1.4
		82	81	-1
Scenario 3	15, 19, 48, 52			
Case 1		78.2	76.3	-1.9
		79.1	78.7	-0.4
		78.2	78.7	0.5
		78.7	77	-1.7
Case 2				
		89.5	87.8	-1.7
		87.6	87.2	-0.4
		92.8	91.2	-1.6
		90.1	90.1	0
Scenario 4	15, 19, 48, 52	97.4	94.4	-3
		92.7	92.3	-0.4
		93.7	94.5	0.8
		96.4	94.1	-2.3
				mean: -1.0
				std: 1.1

6. LIMITATIONS

The application uses a cubic spline function to interpolate sound levels between survey points. This function requires at least 4 points in each dimension, while the linear and the Modified Akima cubic Hermite interpolations require only 2 points in each dimension. For the Modified Akima cubic Hermite interpolation, the interpolated value at a query point is based on a piecewise function of polynomials with degree at most three evaluated using the values of neighboring grid points in each respective dimension. So, the app needs more survey points to generate a contour map than if these other algorithms were used.

The evaluation was conducted in a well-controlled, laboratory setting. The ability of the app to accurately map real-world workplace environments may vary. Factors such as background noise, reflections, and environmental conditions could affect the app's performance in actual workplace settings. Further tests will be performed in workplace with complicate sound environment which has objects like blocks, shelves, walls, etc.

Furthermore, while the study focused on the accuracy of the app in predicting sound levels, other aspects such as user interface, ease of use, and compatibility with different smartphone models could also impact its effectiveness and practicality in real-world applications. Future research could explore these aspects to provide a more comprehensive assessment of the Noise Mapper Application's utility in occupational noise monitoring.

disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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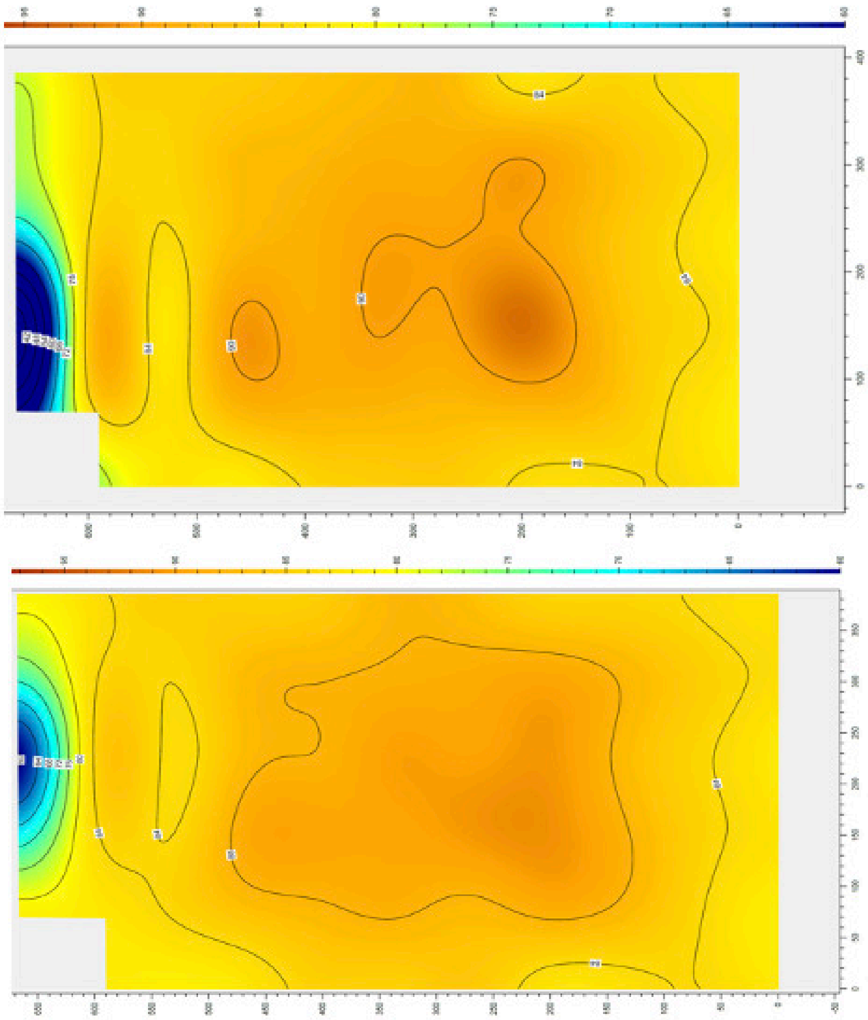

Fig. 9. Sound contour map based on full (top) and partial (bottom) measurements for Scenario 4.

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