Influence of Pavement on Traffic Noise -- Statistical Pass-By Measurements of Traffic on Several Interstate Pavements

Minnesota Department of Transportation

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Elliot B. Dick, Primary Author
HDR Engineering, Inc.

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16. Abstract (Limit: 200 words)

This research project performed statistical pass-by (SPB) measurements of tire/pavement noise influence on overall traffic noise levels. The pavement specimens included in the project were a conventional grind surface, an innovative grind surface, a transverse tine surface, and a burlap drag surface, all located on I-94 to the northwest of Minneapolis. Due to the high volume of traffic on the interstate highway, field measurements were not feasible. An alternative method was adopted of recording video and high-quality audio of all the traffic over several hours, along with a calibration reference level, and analyzing the recorded traffic in the office. This allowed selection of several hundred pass-by events meeting data quality requirements out of the several thousand vehicles present in the recordings. The results showed the innovative grind was clearly the quietest pavement with four-wheeled passenger cars. The results also showed the innovative grind was quieter than most other pavement surfaces, but was inconclusive against the conventional grind with dual-axle and multi-axle heavy vehicles due to insufficient data. On-board sound intensity measurements showed a dBA difference of 4.7 to 5 between the innovative grind and the pre-existing surface texture.

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Prepared by:

Elliot B. Dick
Tim Casey

HDR Engineering, Inc.

Bernard Izevbekhai

Minnesota Department of Transportation

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St. Paul, Minnesota 55155-1899

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The HDR Minneapolis office is grateful to the other HDR offices for lending some of the instrumentation used for this research project. The other HDR offices who contributed the use of their equipment included Phoenix, Portland, and Salt Lake City.

Special thanks goes to Steve Olson of Mn/DOT for his assistance with site access, operating the portable radar sensors, providing site power at MnROAD, and accommodating measurement schedules outside of his usual workday.

HDR Engineering, Inc.
701 Xenia Avenue, Suite 600
Minneapolis, Minnesota, 55416

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Executive Summary

This research project was to measure the influence of some pavement surfaces on the overall traffic noise levels. The purpose of this project was to measure tire-pavement noise on different sections of pavement, each having unique surface finishes, at the MnROAD research facility outside of Minneapolis, Minnesota. MnROAD is the world's largest cold-climate pavement research facility and is operated by Minnesota Department of Transportation (Mn/DOT). The different types of pavements surface finishes include: the conventional grind, the innovative grind, the transverse tine, and a burlap drag. Vehicles travelling northbound on I-94 drive over MnROAD's high-volume pavement test cells. The goal of the project was to compare measurements of tire-pavement noise from selected pavement test cells, and determine how the pavement surface finish affected tire-pavement noise. This was evaluated by a statistical pass-by (SPB) measurement, in conformance with or guided by the International Organization for Standardization (ISO) Standard 11819-1:1997(E) and Federal Highway Administration (FHWA) guidance document FHWA-PD-96-046.

Highway traffic noise is from three primary sources: (1) engine casing noise, (2) exhaust noise, and (3) tire-pavement noise. Other secondary noise sources have varying influence on the overall noise level, such as drive-train noise or aerodynamic noise. The MnROAD research facility has measured tire-pavement noise using on-board sound intensity (OBSI) methods. The OBSI measurements only measure the tire-pavement noise and do not include other noise sources from highway vehicles.

The influence of tire-pavement noise was evaluated by a Statistical Pass-By (SPB) measurement, in conformance with or guided by ISO 11819-1:1997(E) and FHWA-PD-96-046. The premise of SPB measurements is to measure many vehicles as they pass over a particular pavement surface (the pass-by portion of SPB). With a large enough sample set, an average vehicle sound level over the particular pavement type (the statistical portion of SPB) can be determined. Then the difference between measurements of two pavement types only reflects the influence of the tire-pavement noise on vehicle sound levels, but still includes all noise sources of the "average vehicle."

The initial measurement plan was modeled after an FHWA procedure for measuring vehicle noise emission levels, but the extreme high volume of traffic in this section of the I-94 corridor made this an unworkable method in the given time period. The alternative method adopted for this study was to record both audio and video of several hours of traffic, then sort out (in the office) individual vehicle pass-bys out of the thousands of vehicles that passed, and produce measured sound levels. The critical issue for this method is always calibration of sound levels, but is easily addressed by keeping the issue foremost in every aspect of the process.

The results of the SPB measurements showed that a so-called innovative grind pavement surface was quieter than the other measured pavement surfaces. This difference was clear for four-wheeled passenger vehicles. It was also shown to be quieter for dual-axle and multi-axle heavy vehicles, but some specific comparisons are not conclusive due to a small sample size, particularly for dual-axle heavy vehicles.

The results of the SPB measurements showed that a so-called innovative grind pavement surface was quieter than the other measured pavement surfaces. This difference was clear for four-wheeled passenger vehicles. It was also shown to be quieter for dual-axle and multi-axle heavy vehicles, but some specific comparisons are not conclusive due to a small sample size, particularly for dual-axle heavy vehicles.

The following figure shows the comparison of all SPB measurements in this study. There were two measurements of the innovative grind pavement, one of the MnROAD test cell and another test specimen constructed on the regular freeway system in the region. The conventional grind and the transverse-tined pavement surfaces were also test cells at MnROAD test facility. The burlap-drag pavement surface was also measured on the regular freeway system in the region. The regional innovative grind pavement and the regional burlap-drag pavement are referred to as the “subject” and “control” pavements, respectively.

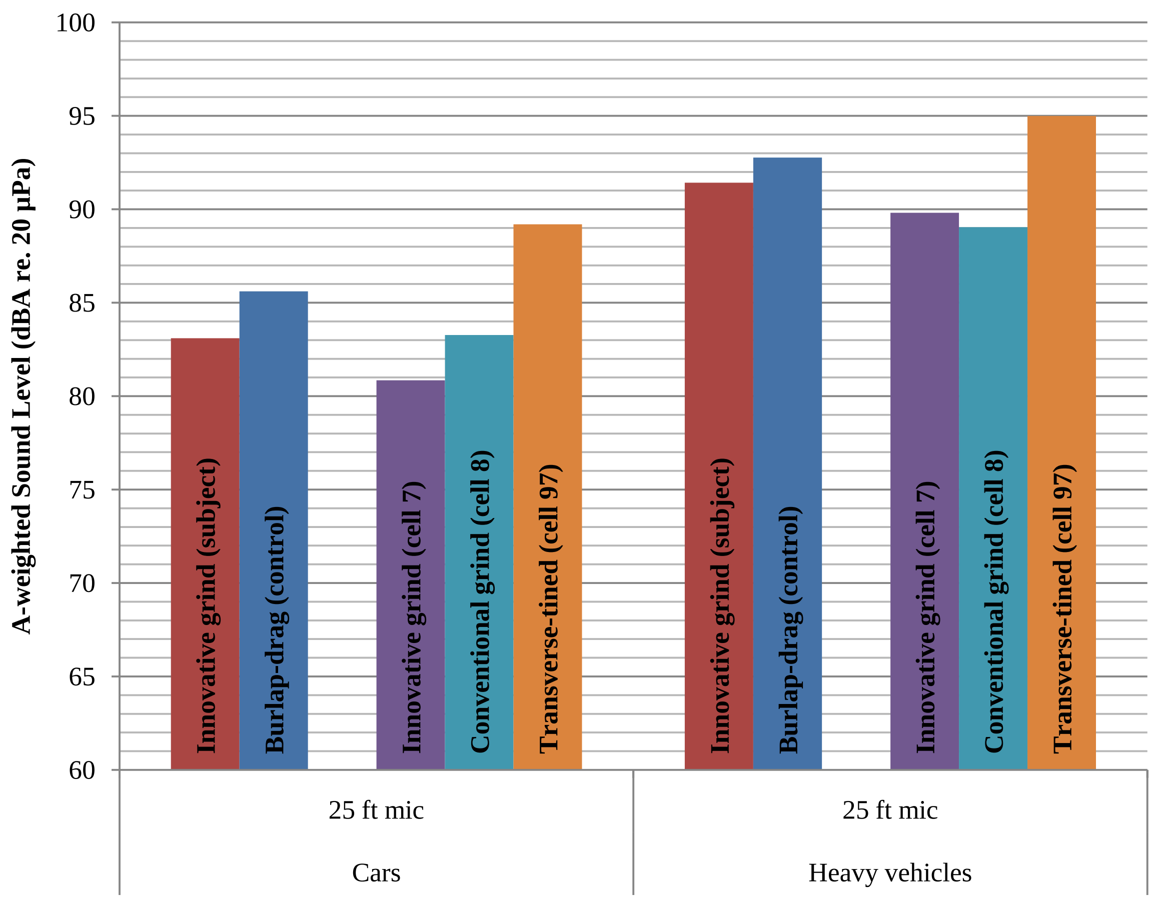

Figure ES.1. Overall comparison of SPB measurements

The preceding figure shows that the innovative grind pavement in the four-wheeled passenger car category is quieter than the other pavement specimens in this study. The qualitative term “quieter” is taken to mean that there is a lower contribution of tire-pavement noise to the overall vehicle noise when traveling over “quieter” pavement. Additionally, the transverse-tined pavement specimen is louder than either the innovative grind specimen or the conventional grind specimen for vehicles in the four-wheeled passenger car category.

The preceding figure also shows that the subject pavement is quieter than the control pavement for heavy vehicles. The heavy vehicle category includes dual-axle and multi-axle heavy vehicles. Another conclusion the data support is that the transverse-tined pavement surface is louder for heavy vehicles than either the innovative grind or the conventional grind. The data are inconclusive about the difference between the innovative grind and the conventional grind for heavy vehicles.

There is a notable difference in levels for the two innovative grind pavement specimens MnROAD versus St. Cloud Test Section) in both vehicle categories. This may be partially attributable to random errors between the two measurements, but there are also likely differences between the two pavement specimens, particularly because the subject pavement specimen was very recently refurbished with the innovative grind, and the MnROAD test cell 7 is more established. Given that concrete surfaces generally get quieter over time, this difference between the two nominally identical surfaces is not surprising. Parallel OBSI results in the Appendix D show a range of OBSI difference of 4.7 to 6 dBA between the previous texture and the innovative diamond ground texture. It must be noted, therefore, that OBSI captures the difference between the tire pavement interaction sources for various texture types. Beyond the source, the higher frequency component of OBSI attenuate quickly and only a comparison of the lower frequency difference is made at a receiver at a reasonable distance from the source. Nevertheless the quieter pavements result in quieter overall noise.

Chapter 1. Introduction

This study collected statistical pass-by (SPB) measurements of tire-pavement noise from moving vehicles to identify the net differences of overall traffic noise associated with different pavement surfaces. In the summer and fall of 2009, HDR performed statistical pass-by measurements on several pavement specimens. Postprocessing, data reduction and data analysis continued through the fall and winter.

Chapter 1 outlines the research issue, the research goals, the basic approach, and the report organization. Chapter 2 describes the measurement standards, the challenges associated with high-volume roads, and the adapted measurement method. Chapter 3 identifies the measurement sites included in the Study. Chapter 4, Chapter 5 and Chapter 6, respectively, describe the field data capture, data reduction and data analysis processes. Chapter 7 presents the results of the Study. And Chapter 8 discusses the results.

Appendix A details the pavement specimens included in this study. Appendix B lists the equipment used throughout this measurement. Appendix C details the regression parameters for each SPB measurement. Appendix D details the regression parameters for the differences between paired observations.

Background

Road vehicle noise emission comes from three primary sources: engine casing radiated noise, engine exhaust noise, and tire-pavement noise. The Minnesota Department of Transportation (Mn/DOT) Office of Materials Research identified a pavement surface which produces characteristically less tire/road noise. They have finished a test cell in their MnROAD test facility with this pavement surface, and recently refinished a 1000’ segment of pavement on the I-94 freeway for testing. If this pavement surface reduces the overall vehicle noise, there may be less mitigation required and may result in a cost savings, however the cost analysis is not part of this study.

Mn/DOT has measured the tire-pavement noise using On-Board Sound Intensity (OBSI) measurement methods. However this only measures the tire/road noise and disregards the engine casing and exhaust noise of vehicles. States determine noise mitigation requirements by analyzing community noise levels due to the overall vehicle noise level, which is the sum of the tire-pavement noise, the engine casing noise, and the exhaust noise of vehicles.

To confirm that less tire/road noise will contribute to a lower overall vehicle noise emission level, Mn/DOT hired HDR to conduct SPB measurements for this quieter pavement surface and several other pavement surfaces for comparison. SPB measurements are an internationally standardized measurement method which allows a comparison of the influence of tire-pavement noise on the overall vehicle sound emission level.

Objectives

The objective of this study is to conduct statistical pass by noise monitoring and data analysis to make relative comparisons of various pavement surfaces. This study performed two sets of SPB measurements.

One set of SPB measurements took place on select interstate test sections at the MnROAD facility. The SPB data was used to identify the net differences of overall traffic noise associated with each pavement surface. Furthermore, the measurements are “paired” in that the vehicles which comprise the sample set at each measurement site are identical.

Because the pavement test cells at MnROAD are only 500 feet apart, noise from traffic on an adjacent pavement test cells may affect noise from traffic on the subject test cell. The methodology was largely successful in off-setting these blending effects.

The other set of SPB measurements was intended to fully demonstrate that the quietest test pavement surface reduces overall traffic noise levels, outside of the small-size pavement cells of the MnROAD test facility. Therefore a section of pavement longer than 500 ft was installed with the subject pavement surface finish on a high speed roadway in the region. The measurement of this pavement surface was compared with an equivalent section of high-speed roadway in the region with a control pavement surface finish.

Pavement noise will also compare certain pavement types without a grinding finish and with a grinding finish. These sections of pavement will be measured using the same SPB measurement method. This will serve to verify the pavement noise level under conditions more representative of actual pavement installations.

The measurement procedures conformed as closely as possible to ISO Standard 11819. Furthermore, most requirements in the document FHWA-PD-96-046 were also met; this enables the underlying data to be potentially used in the future for determining the reference energy mean emission level (REMEL) of these vehicle-pavement combinations.

The SPB measurements occurred under free-flowing interstate highway traffic conditions over the pavement specimens of interest. The measurement included digitally recorded noise from traffic on each individual section of unique pavement surface. A rigorous review of the data identified the unique spectral characteristics of the different pavement test specimens, and should allow ranking the pavements in terms of relative loudness.

Chapter 2. Measurement Method

The general premise of a statistical pass-by measurement is to measure the noise levels from a large number of vehicles passing over the pavement specimen of interest. With a large enough sample size, it is reasonable to infer that the average of the vehicle noise emission levels from this sample set is the noise emission level of an average vehicle on the particular pavement specimen. In other words, the average measured vehicle noise in the sample set is a typical vehicle's noise emission from the vehicle engine casing noise, exhaust noise and other incidental noise sources. But the difference of this sample set can be attributed to the tire-pavement noise contribution to the overall vehicle noise emission.

Measurement Standards

The measurement procedures conformed as closely as possible to ISO Standard 11819-1:1997(E), *Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: statistical pass-by method* (hereafter referred to as ISO 11819). Furthermore, the measurement procedures met most requirements in the document FHWA-PD-96-046, *Measurement of Highway-Related Noise*, specifically from Section 5, "Vehicle Noise Emission Level Measurements for Highway Noise Prediction Models" (hereafter referred to as FHWA-PD-96-046).

The general premise for capturing data is very similar between these two measurement methods. It is to capture a sample set of vehicle pass-by noise levels. There are congruent requirements between the two methods for measurement site characteristics, microphone locations, vehicle classification, instrumentation characteristics and setup, and pass-by event quality. But while the data capture and reduction methods are similar, the purpose of the data analysis differs between the two measurement methods.

In FHWA-PD-96-046, the purpose is to create a noise emission level curve against vehicle speeds to be used in highway noise models. The noise emission curve is not a simple linear regression because it needs to be based upon the full range of potential road speeds. In the case of this study, we are only measuring the high-speed interstate traffic. Therefore this type of analysis is omitted from this project.

In ISO 11819, the purpose is to evaluate or compare the noise characteristics of different road surfaces, in the context of the tire-pavement noise contribution to the overall traffic noise. There are three potential road speed categories; and the analysis for each category is a simple linear regression. The I-94 interstate traffic speeds are typically above 100 km/h (62 mph), which is defined in ISO 11819 as the High road speed category. This study only analyzed traffic according to the High road speed category.

High-Volume Measurement Challenges

Most of the requirements or recommendations of ISO 11819 and FHWA-PD-96-046 are reasonably achievable with appropriate resources. The specific requirements and recommendations are all addressed under appropriate headings throughout this report. However one challenge that became apparent during planning was achieving high-quality pass-by events in terms of acoustic measurements. This was due to the very high volume of vehicle traffic.

The event quality requirements ensure that the acoustic measurement of the vehicle is truly a measurement of only that vehicle's noise emission. This requires that the vehicle be alone, without other vehicles during the pass-by. The presence of other vehicles would elevate the acoustic measurement, and consequently they would artificially increase the noise emission of that vehicle.

To ensure that other vehicles do not influence the noise level during the pass-by, both the ISO and FHWA measurement method prescribes that the vehicles be clearly distinguishable from one another. This means that just prior to and after the passing of a vehicle, a minimum noise level rise and fall is required. To help meet these criteria, the FHWA method further recommends that there be a minimum separating distance in-between vehicles.

On I-94 near Albertville, the daily traffic volume in the summer often falls between 13,000 vehicles and 17,000 vehicles in one direction, according to June, 2007 westbound traffic data. Even during non-peak daylight hours, there are frequently more than 600 vehicles per hour. Additionally, the vehicles were not evenly distributed; they tended to pass in clumps. Lone vehicles were extremely rare during measurements performed for this study.

But some vehicle clumps were not as dense as others, or had stragglers or a leader pulling away from the pack. These vehicles would have to provide the pass-by events for the acoustic measurement. The challenge was figuring out how to, in just a couple of seconds, record all the data required about the pass-by, look at the time-trace to evaluate the acoustic suitability, make a decision and record the maximum pass-by level. This was a daunting task to achieve several hundred times in the field.

Adapted Measurement Procedure

Instead of attempting to identify qualifying pass-by events in the field as they happened, HDR decided to capture high-quality audio recordings of all the traffic, along with video recordings. This method is used most frequently in product noise emission measurements or in architectural measurements.

The video was used to classify the vehicles and to ensure that disturbing vehicles were not present near the vehicle of interest. The audio recordings were analyzed to ensure the acoustic criteria for event quality were met. This gave HDR the ability to address those pass-by events one or more times as necessary to ensure that they did meet all the event quality criteria. The playback could be paused to record all the other information about the pass-by event. This method facilitated successfully selection of hundreds of high-quality vehicle pass-by events out of thousands which passed by in just a couple of hours.

There is also guidance in ANSI S1.13-2005, *Measurement of Sound Pressure Levels in Air* which covers recording a sound in the field for later analysis in the laboratory or office. This guidance includes recording-equipment characteristics, qualification methods for recording equipment, and procedures for field-recording. The adapted measurement procedure followed this guidance in executing this Study.

Measurement Uncertainty

Measurement uncertainty is outlined in ISO 11819, Clause 9.6, as found by pre-normative research. The largest source of random error is expected from individual vehicle differences within each vehicle class, specifically different engines and exhaust systems, different tires, and different conditions of upkeep. To ensure an average of these factors, so the largest consistent variation is the road surface itself, a large enough sample size is required to obtain an average of the vehicle variances. To obtain this average, minimum numbers of pass-by events are prescribed by ISO 11819 for each vehicle class (Clause 7.3) as follows.

- Category 1 (Cars): min. 100
- Category 2a (Dual-axle heavy vehicles): min. 30
- Category 2b (Multi-axle heavy vehicles): min. 30
- Categories 2a and 2b together (Heavy vehicles): min. 80

The regional pavement measurements exceeded or came very close to these minima. The measurements at the MnROAD test cells were short of these minima. However the MnROAD test cells were paired measurements, which usually are able to achieve significance with much smaller sample sets. But the uncertainty levels of paired measurements are not defined in ISO 11819, and would have to be determined by an additional statistical analysis on these data and other paired measurement sets.

Chapter 3. Pavement Measurement Sites

A measurement point was selected on the centerline of the vehicle travel lane (the right-hand lane, nearest the microphones). This was the focus of the measurement and all dimensions are relative to the measurement point. The measurement sites were as similar to each other as reasonably achievable, including ground conditions, vegetation, and atmospheric conditions at the time of measurement. Site requirements include:

- There could not be acoustically reflective surfaces near the measurement point, within at least 30 m (100 ft). This included any vehicles used in connection with the measurement program.

- The ground must have the same or similar absorption properties as the pavement under test from the centerline to at least 3.75 m (12.5 ft) from the centerline of traffic.

- Locations were evaluated for influence by potential acoustic interferences, including nearby noise sources.

- Locations were superficially evaluated for electromagnetic radiation such as from nearby high voltage transmission lines or television or radio towers.

- Barriers were expressly avoided, including fences and guard rails. Barriers of this type would need to have been temporarily removed during measurements.

- The microphone should have 150° of unobscured line-of-site to the centerline of travel. To meet this with the furthest microphone (100'), there must be at least 112 m (375 ft) of clear, straight road on either side of the measurement point.

The FHWA-PD-96-046 document prescribes the attendant(s), the instrumentation, and the radar gun be positioned at a point 120 m (394 ft) upstream of the measurement point. Positioning the instrumentation 120m away is unrealistic due to cabling requirements. Interference by attendant was the primary concern (self-generated noise). To avoid this, the attendant was positioned at least 30 m (100 ft) away and was conscious of noise interference throughout the measurement. This position complied with the requirements of ISO 11819.

Regional Measurement Sites

Two measurement sites were selected for the regional pavement specimens. There was a 1000 foot section of concrete pavement which received the innovative surface-grinding. Another section of pavement was selected which was the same material as the ground section, but without surface-grinding. Both measurement sites were northwest of MnROAD.

These locations were not considered a paired measurement. To be a paired measurement there must be identical vehicles traveling over each pavement specimen. The measurements occurred on different days. Identical vehicles will not travel on the specimens on the different days. Additionally, even if there were to have occurred on the same day, there were freeway entrances and exits between the two sites, so there wouldn't be exactly matching traffic at the two sites. However, these measurements captured a large enough sample size to obtain an average vehicle for each class, and provide a valid comparison.

Regional Subject Pavement

There was a 1000 ft. section of concrete pavement between mile markers 192 and 191 which received the innovative grind on its surface. The measurement location was in the middle of the 1000' test section, with microphone locations to the north (on the westbound traffic). A technical description of this pavement type is provided in Appendix A.

This section was on a slight grade and a subtle curve. The incline was approximately 3 to 5 feet over the 1000 foot section, less than the 1% maximum grade prescribed by ISO 11819. The curve is insignificant and can be described as a "slight bend" deemed acceptable by ISO 11819. The primary stated concern of document FHWA-PD-96-046 is a site with constant-speed traffic, and the incline and slight bend were not observed to cause vehicles to change speeds through it.

There was a berm to the north, but not within 100' of the lane of traffic. There were also residences on the other side of the berm. This was initially assessed as insignificant due to the relative positions of the microphones, the berm, and the angle of the housing surfaces. The primary reason that the reflecting surfaces of the residences were assessed as insignificant was because the microphone elevations were all below the elevation of the top of the berm. Therefore the berm should have interrupted any reflections off the residences. However the site may have influenced the measurements, whether from reflections off the residences or from other site geometries. More discussion of the possible site influence is provided below in the results. In any case the site was not negotiable, since this was the only section of road with the innovative grind.

Regional Control Pavement

A suitable site was selected which had the same material and finish as the subject pavement, but without any surface grinding. This was a concrete pavement with a burlap-drag surface finish. A site was selected on a straight, flat section of I-94, between mile markers 194 and 195. A technical description of this pavement type is provided in Appendix A.

The measurement site for the Control pavement surface was located with a church and big-box hardware store on the other side of a berm to the north, and an open field to the south. The measurement location was on the eastbound traffic, with microphone locations to the south. Measuring on the westbound side of I-94 was not an option due to the berm on the north side, which did not allow the 100' microphone to sit at the correct elevation.

There were a couple of road signs on the south side – two that are parallel with the traffic, each 318 feet from the measurement point, and two larger signs/billboards perpendicular to the lanes of traffic that are greater than 500 ft from the microphone location. These distances exceed the minimum for vertical reflective surfaces required by the standard ISO 11819 and recommended by the document FHWA-PD-96-046.

MnROAD Test Cells

The MnROAD Test Cells are short sections of pavement at the MnROAD test facility. The term cell refers to the individual pavement test section that is approximately 500 feet long at MnROAD. The regular interstate traffic travels over the test cells, thus the section of test cells is referred to as the MnROAD Mainline. There are temporary diversions of westbound traffic onto bypass lanes for maintenance and monthly pavement testing, but otherwise traffic travels over the test cells on a nearly constant basis. Most Cells are 500’ long or less. The entire length of the test cells is straight and flat.

Opposing traffic is much further away than usual for a divided interstate highway, because the bypass lanes are situated between the eastbound and westbound mainline, and all three are separated by wide ditches. Therefore interfering noise from opposing traffic was not a concern except for the loudest trucks.

HDR performed two sets of paired traffic recordings. The first set simultaneously recorded traffic over three test cells: Cell 97 (transverse tine), Cell 8 (conventional grind) and Cell 7 (innovative grind). The second set simultaneously recorded traffic over two test cells: Cell 7 (innovative grind) and Cell 4 (Superpave). Only the data for Cell 97, Cell 8 and Cell 7 were postprocessed, reduced and analyzed for comparisons. The data were recorded to compare Cell 7 and Cell 4 in the future. Technical descriptions of these test cells’ pavements types are provided in Appendix A.

The physical characteristics of the sites at Cells 97, 8 and 7 were fairly homogeneous, in terms of the shoulder and ditch configuration, and a convenient road on the other side of a fence to access the sites. The physical characteristics of the measurement site at Cell 4 are somewhat different in terms of the absence of a ditch. This only potentially affects the 50’ microphone position, the 25’ microphone position was still fairly close to the shoulder of the road in a similar manner as the other sites.

Measurement Schedule

The measurement schedule was largely dictated by atmospheric conditions and anticipated traffic volumes. Measurements could not occur in precipitation, or for at least 36 hours after precipitation, because a prerequisite for the measurements is dry pavement. Measurements also needed to avoid days with excessive wind which would cause turbulence noise around the microphones, even with windscreens. Therefore the schedule remained fluid to accommodate weather forecasts.

Traffic Volumes

MnROAD provided traffic weigh in motion (WIM) sensor data from their database, identifying vehicle types, speeds, and lanes of travel. The data spanned the entire month of July, 2007, except for three days of diverted traffic. An analysis of this data showed that Friday traffic volumes were too large to effectively deal with SPB measurements. Thursday had a lower volume than Friday, but still had excessive traffic for SPB measurements.

Monday through Wednesday appeared to have fairly consistent traffic volumes, much lower than Friday and Thursday. Looking at Mondays, Tuesdays and Wednesdays in detail, there was very low overnight traffic. Passenger car and heavy truck traffic increased in the 5:00 AM hour or the 6:00 AM hour, and increased at a slow rate through the 12:00 PM hour. The passenger car traffic volume increased notably from around 1:00 PM through the 4:00 PM hour, when the hourly traffic volume peaked.

Daylight was required for the video camera to accurately record vehicles as they pass by. Based upon this, the review of traffic WIM data, and supported by visual traffic observations, the best likelihood of capturing pass-by events on westbound traffic was on Mondays, Tuesdays and Wednesdays, beginning at 6:00 AM, and ending between 12:00 PM and 1:00 PM. This required arriving on site in the dark to set up the recording systems.

For eastbound traffic, similar traffic volume behavior was assumed, even though the rush-hour should peak in the morning not the afternoon. Indeed there were some higher-volume hours before midmorning, but the noise interference from westbound traffic started to increase after midday and required the recording to be stopped.

Chapter 4. Data Capture

The field data-capture team consisted of two acoustic instrumentation attendants, and for the regional measurement sites one or more Mn/DOT staff was present to attend to the radar traffic sensor. The measurement equipment included the acoustic instrumentation, the field recording equipment, and support equipment. A list of NIST-traceable instrumentation is provided in Appendix B.

Acoustic Instrumentation

The microphones selected for the recording were instrumentation microphones normally used for environmental noise measurements. The microphones had a nominal frequency response range that included the range of frequencies from 50 Hz to 10 kHz. The microphones were all free-field microphones to provide uniformity in measurement. The self-noise of the microphones was less than 20 dBA (re. 20 μPa) to ensure adequate signal-to-noise when the signal is highway traffic noise. A microphone windscreen was utilized, compatible with the microphone system.

The microphones and the preamplifiers were provided bias voltage from sound level meters. The analog waveform of the microphone audio passed through the "A/C Out" output of the sound level meters. The sound level meters were set to pass the waveform with linear weighting, in other words the audio signal passed through the meter without modification. Gain was not added to the Larson-Davis model 820 sound level meters or the Larson-Davis model 824 sound level meters, and the dynamic range of the Larson-Davis model 2900 meter was adjusted to prevent signal clipping.

A battery-operated precision microphone calibrator was used to record a reference level for each microphone position. The reference level calibration was traceable to the National Institute of Standards and Technology. The microphone calibrator conformed to the requirements of ANSI S1.40 and IEC 60942, Class 1 Sound Calibrators.

Primary Calibration of Acoustic Instrumentation

HDR handheld calibrators receive primary calibration on an annual basis by an independent laboratory using standards traceable to the National Institute of Standards and Technology All other HDR sound measurement equipment, including meters/analyzers and measurement microphones, is typically calibrated on a biannual basis. Calibration certificates are available upon request.

Recording Equipment

The recording platform was a laptop running an audio recording and editing software suite (ProTools), with an analog-to-digital converter connected to the laptop via firewire. The digital recordings were 16 bit, 44 kHz resolution. The A/C output of the sound level meters was connected to individual inputs of the converter. Gain settings of the converter were adjusted so the calibration tone was below clipping-level. Sound levels were not measured above the level of the calibration tone.

Support Equipment

Mn/DOT staff provided a radar system for vehicle speed logging of the regional pavement measurement sites. A consumer-grade handheld video recorder was used to record all traffic during the data capture to DVD media. The audio signal of the video recorder was also utilized as a memo track, to record verbal commentary or verbal markers for synchronizing tracks.

A handheld anemometer was used on site to check wind gust speeds. Headphones were used both on-site and during playback to ensure that wind noise or other non-traffic noise did not interfere with the measurements.

Equipment Setup

HDR and Mn/DOT determined the measurement point on the centerline of the vehicle lane of travel. From this measurement point, three microphone positions were erected perpendicular to the vehicle travel centerline, at distances of 7.5 m, 15 m, and 30 m (25 ft, 50 ft, and 100 ft, respectively). The 7.5 m location conforms to ISO 11819, and the 15 m distance is the primary microphone location prescribed by FHWA-PD-96-046. The 30 m location is suggested by the FHWA method, and is also identified in the measurement project which produced the national REMEL results used in the FHWA Traffic Noise Model.

Microphones were mounted on a stand sufficiently strong to support the weight of the microphone and accessories mounted on it and which was resistant to being upset by the wind or other disturbances. The microphone stand was either a tripod, or a mast with a tripod base, depending upon the needed height. As an added measure of stability, a tent stake was driven into the ground under the 25’ microphone position, and the stand was secured to the stake by a bungee cord.

The microphones were mounted at a height 1.2 m (4 ft) above the pavement surface. This required different heights of microphone stands to accommodate the ground contours. At the 25’ microphone position, the stand was still located on the shoulder of the road, though not on the pavement. At the 50’ microphone position, the ground was often in a ditch, lower than the pavement surface, and so needed a taller stand.

All three microphones were powered by analyzer systems, and the audio outputs (AC outs) of the analyzers were recorded in a digital recording system. Long microphone and audio cables were required to ensure that the measurement attendant and the support vehicles were more than 100’ away from the microphones.

The video camera was located near the measurement attendants and aimed towards the traffic and the nearest microphone location (the 25’ microphone location). This captured the traffic in both lanes as they passed in front of the nearest microphone. The only exception was the paired measurement between test cells 7 and 8 – only one video camera was aimed straight at the road in-between the two cells. Despite not having a direct video image of the microphones, the event quality can be assured by having both the video image and the recorded audio at both sites comply with all event quality requirements and discarding those which are questionable to any degree.

The vehicle logging radar system was located 150 ft to 250 feet upstream of the noise measurement equipment, despite the ISO and FHWA methods prescribing the speed measurement at the same point on the lane of travel where the microphones are located. At highway speeds, there was not enough distance between the speed measurement location and the acoustic measurement location that drivers could dramatically change vehicle speed. However, in the interest of thorough documentation, note that the precision and accuracy of the speed data may be modestly affected by this offset distance from the acoustic measurement point. The data collected by the radar system were provided to HDR to use with the analysis. This radar system was not included in the MnROAD test-cell measurement sites.

After identifying that the 100’ microphone position captured very few pass-by events which met the minimum event-quality criteria, this position was abandoned for the MnROAD test-cell measurement sites. For measurements at the MnROAD facility, two microphone positions were utilized at two or three simultaneous test-cell measurement sites. Cell 7 and Cell 8 were adjacent test-cells, and very long cables allowed all four microphones to be recorded into one unit. Cell 97 and Cell 4 were not adjacent to other test-cell measurement sites and a separate recording system was used at this site.

Recording Procedures

Once all equipment was operational in the field, calibration tones were recorded. The windscreen was removed and the microphone calibrator was fitted snugly over the microphone. A short time interval was allowed to pass (approximately 30 seconds), in case there was any time required to equalize pressure around the microphone diaphragm. Then the calibration tone was activated.

At the initial calibration recording for each measurement site, the recording gain was adjusted so the calibration tone was not clipping. Then the calibration tone was recorded to the microphone track. After this initial calibration for each track corresponding with a microphone position, gain settings were considered fixed – no further gain adjustments could be allowed. But calibration tones were recorded for each microphone track between every hour of traffic recording without any further gain adjustments, and again at the end of the recording session without further gain adjustments.

The traffic was recorded continuously for hour-long or half-hour long intervals. The video recording was started first and audio commentary provided the measurement identification and time markers to synchronize the other recorded audio tracks. During recording, the measurement microphone audio was monitored on headphones to observe any potential non-traffic noise interference, especially wind-generated noise or attendant-generated noise. Also during recording, traffic was observed to count the number of vehicle pass-by events likely to qualify for inclusion in the data set. Measurements were paused or stopped to allow HDR to check or reset monitoring/recording equipment or software, and then new recordings were started.

In addition to monitoring the measurement microphones for wind-noise interference, the handheld anemometer was used to check wind speeds. In the absence of more specific guidance by the windscreen vendor or manufacturer, the wind speed at which interference generally does not occur is speeds less than 20 km/h or 12 mph. Wind speeds remained below this level throughout all recordings.

Chapter 5. Data Reduction

Postprocessing and data reduction tasks occurred within a single process using desktop equipment. The video and all audio tracks were synchronized, events were picked out of the recorded traffic based upon the event-quality criteria, traffic information was recorded about the event, and acoustic measurements were performed on the event. This resulted in a vehicle database consisting of the vehicle information and its corresponding acoustic measurement.

Acoustic Instrumentation

The measurement equipment was a Sound Level Meter (SLM) conforming to the requirements of Type 1 instruments as defined respectively by ANSI S1.4 and IEC 60651. Filters conformed to the requirements of ANSI S1.11.1985 and IEC 61260. The SLM had the capability to store analysis results, at least a 60-dB dynamic range, frequency-weighting capability, and measured with the Fast (125 ms) exponential time averaging constant. Spectral sound level measurements were made in the one-third octave-bands between 50 Hz to 10 kHz center frequencies to conform to ISO 11819.

Postprocessing (Playback and Measurement) Procedures

The desktop configuration for measurement was the PC-based recording and editing software suite with a digital-to-analog converter. The output of the converter was connected to the input of the sound level meter. The sound level meter was adjusted to the field-recording of the calibrated reference level.

The video and the memo track for each location were automatically synchronized. The recordings of the measurement microphones at each location were also synchronized. The video and the measurement tracks were synchronized using verbal markers in the memo track. The synchronization was manually verified so that the sound and the video were correct within a second or two according to pass-by timing and the general sound of the vehicle that passes by. Only one synchronization attempt failed with observation of sound occurring without video of vehicles, big trucks making the sound of small cars, etc. In this case, the synchronization was restarted from scratch and subsequently produced successfully synchronized audio and video tracks.

Calibration

Before measuring the sound levels of vehicle pass-by events, the sound analyzer is calibrated. The calibration tracks recorded before, after and between each hour of traffic recording were utilized for calibrating the acoustic instrumentation. Calibration tones are unique to each microphone location recording, so the meter was calibrated with the appropriate tone into the corresponding analyzer channel, and recalibrated when changing playback tracks or analyzer channels.

Each microphone recording track has a unique calibration level, depending upon the microphone sensitivity and the gain settings of the signal chain. Audio signal gain settings may be provided by the preamplifier, the microphone power supply, the recording system and the playback system. These gain settings were only adjusted during the recording sessions prior to the first calibration tone recording for each track. And likewise during the playback sessions the gain settings were not adjusted after the calibration level was set on the analyzer. Calibration of the analyzer was performed at least once on each day of playback measurement to ensure correct measurements.

Adjustments due to calibration drift were not necessary. Calibration drift for the recorded signals would manifest itself in a change in the recording gain or playback gain. The hourly calibration tones would show evidence of calibration drift. Calibration drift in the recording system was not more than 0.2 dB. Calibration readings may not differ by more than 0.5 dB to be considered valid under ISO 11819, and may not differ by more than 1.0 dB according to FHWA-PD-96-046. Because it fell under these criteria, no recordings were discarded or adjusted to compensate for calibration drift.

Pass-By Screening

The entire video was observed while listening on headphones to screen for candidate pass-by events. The target vehicle for a candidate event had to be an isolated vehicle. The video of the candidate pass-by event was evaluated to ensure that the vehicle is in the driving lane in the direction of travel in the video, the vehicle is the only vehicle in either the driving lane or passing lane in the direction of travel in the video, and there are no trucks or vehicles louder than a standard passenger car in the lanes of traffic in the opposite direction. The audio recording is aurally evaluated to clearly identify a single vehicle event, either by no vehicle noise ahead or behind the vehicle of interest, by clearly identifying the aural peak and a fall of sound level before the sound level begins to rise for the vehicle of interest, and clearly identifying the aural peak and a rise of sound level after the sound level begins to fall for the vehicle of interest.

Candidate pass-by events which resulted from the pass-by screening were marked, and data were recorded to begin the vehicle's database entry. This included time of the pass-by, the vehicle type, preliminary speed information, and assigning a unique identifier to the vehicle pass-by event.

Vehicle Categories

Vehicle categories were recorded in the vehicle database using the following categories:

Automobiles/Cars: All vehicles with FHWA designation 'A' have two axles and four tires and are designated primarily for transportation of nine or fewer passengers, i.e., automobiles, or for transportation of cargo, i.e., light trucks. Generally, the gross vehicle weight is less than 4500 kg (9900 lb). All vehicles with the ISO 11819 designation '1' are passenger cars excluding light vehicles. These are generally equivalent categorizations.

Medium Trucks: All cargo vehicles with FHWA designation 'MT' have two axles and six tires. Generally, the gross vehicle weight is greater than 4500 kg (9900 lb) but less than 12,000 kg (26,400 lb). All vehicles with the ISO 11819 designation '2a' are trucks, busses and coaches with two axles and more than four wheels. These are generally equivalent categorizations except for buses (see below).

Heavy Trucks: All cargo vehicles with FHWA designation 'HT' have three or more axles. Generally, the gross vehicle weight is greater than 12,000 kg (26,400 lb). All vehicles with the ISO 11819 designation '2b' are trucks, busses and coaches with more than two axles. These are generally equivalent categorizations except for buses (see below).

Buses: All vehicles with FHWA designation 'B' have two or three axles and are designated for transportation of nine or more passengers. Very few of these events were captured, so these were considered supplementary data and not included in the analysis data set.

Motorcycles: All vehicles with FHWA designation 'MC' have two or three tires with an open-air driver and/or passenger compartment. Very few of these events were captured, so these were considered supplementary data and not included in the analysis data set.

Event Quality Assessment

Measurements were only taken on individual vehicle pass-by events which could be clearly distinguished acoustically from other traffic on the road. The pass-by screening process isolated many candidate pass-by events for inclusion in the sample set. The events were evaluated in more detail in a second review of the video for these isolated candidate events. Vehicle measurements were discarded when the following was observed in the video or audio.

- Other vehicles overtake the target vehicle or pass the target vehicle in the other lane.

- Individual vehicles which clearly exhibit unusual or atypical noise characteristics such as might occur due to a faulty exhaust system, vehicle body rattles or audible warning devices, or vehicles with auxiliary equipment which emits audible sound.

- Individual vehicles judged not to be moving at constant speed, such as accelerating or braking vehicles.

- Individual vehicles judged to deviate significantly in their lateral position from the median axis of the test lane.

- Other noise interferences are observed in the video or audio.

If the candidate event is not otherwise discarded, the event is assessed for acoustical quality. The intent of the acoustic quality is that the noise of the target vehicle is 10 dB greater than any other noise present at the microphone position. To achieve this, the maximum measured noise level of the vehicle pass-by must meet two criteria: sufficient signal-to-noise ratio, and be clearly distinguishable from disturbing vehicle noise levels.

To be considered a sufficient signal-to-noise ratio, the maximum sound level of an individual vehicle must exceed the background noise level by more than 10 dB. Then to be clearly distinguishable from disturbing vehicle noise levels, the A-weighted sound pressure level just prior to and just after the passage of a vehicle intended for measurement must reach a level at least 6 dB below the measured maximum A-weighted sound pressure level during the pass-by. This will ensure that at the time when the maximum sound level is generated, the collective sound from other traffic will be at least 10 dB below the registered maximum level and will therefore have negligible effect on the measured level.

The 6 dB rise before and fall after the pass-by event is a requirement of ISO 11819, Clause 7.2. Event quality types are also standardized by FHWA-PD-96-046, Clause 5.4, according to the rise in level before the event, and the fall in level after the event, whichever is less: Type 0 is a 3-6 dBA rise/fall difference, Type 1 is 6-10 dBA, and Type 2 – the highest quality – is greater than 10 dBA rise and fall differences. By these definitions, the ISO criterion falls within Type 1 and Type 2 event quality. FHWA also only allows Type 1 and Type 2 quality events, though provisionally allows Type 0 quality events with additional processing. This Study followed this classification and included Type 1 and Type 2 quality events in the sample set.

To evaluate the acoustic event quality each region is individually played into the sound analyzer, by vehicle and by microphone track, to determine the event quality type. The meter is set to display the fast-averaged, overall A-weighted levels in a rolling time-history. The meter range and display range and scales are adjusted to best observe the rise and fall of each event in the time-history. Only relative levels of the rise and fall of each event are of concern for this purpose, absolute levels are disregarded at this point.

The events in the vehicle database for the 25 ft microphone position are all type 1 or type 2 event quality. Often the same events at the 50 ft microphone position did not have event quality according to the above criteria, and so many of the 50 ft microphone events must be discarded, where the same event at the 25 ft location is utilized in the sample set. The event quality of the 100 ft position rarely qualified to be included in the sample set, and these events were not analyzed. Nonetheless, the events at the 100 ft microphone are retained for informational purposes if a future study examines sound propagation at the sites.

Paired Events

For the MNROAD measurements, the sample set was comprised of single vehicles which passed in front of all locations. The single vehicle had to meet the event quality requirements at all measurement sites. This eliminates vehicles that may meet criteria at one location but not another. This was an added dimension to the postprocessing and data reduction process.

Event Measurement

After calibration, the analyzer was set to capture the 1/3 octave band spectrum at the maximum A-weighted level of the event. This was intended to represent the noise emission spectrum when the vehicle was closest to the observation location. The audio recording of each qualifying vehicle is then played into the running analyzer, and each spectrum is saved as individual records. Data collected at the 25 ft microphone location was measured in channel 1 and data collected at the 50ft location was measured in channel 2 of the LD2900. Successful measurements were stored for later inclusion in the vehicle database.

Vehicle Database

Each qualifying vehicle pass-by event is defined as a small region of the overall audio recording. The digital recording and playback platform provides instant access to any defined region (pass-by event). Each region is identified within its name by the assigned unique vehicle identification, the elapsed time in the recordings, the vehicle classification (using FHWA abbreviations), the microphone position, and the event quality type.

Regions were exported as wave files for later reference and archival purposes. Note that the waveform of the exported sound may not begin or end at zero – that is, there may be a non-linearity to the waveform at the beginning and end which may produce the sound of a click or pop. If using these recordings for playback, the non-linearity is easily avoided by waiting to start the meter just after playback begins and stopping the meter before the playback ends.

The vehicle pass-by data were compiled into a vehicle database, separated by pavement specimen and microphone position. The specific data included in the database are the unique vehicle identifier, its speed, the vehicle category, the event quality type, and the 1/3-octave-band sound-pressure levels. The vehicle database is in a spreadsheet file, containing the above data for each measured vehicle pass-by event.

Chapter 6. Data Analysis

The data analysis is a normalization of the vehicle pass-by database using statistical methods. As previously noted when discussing the measurement standards, the data analysis conforms to ISO 11819 for “high” road speed categories, and does not follow the method in FHWA-PD-96-046. Despite the similarity of both methods for capturing and reducing the pass-by event measurements, the character of the data collected is only suited to analysis by the ISO 11819 methodology.

Linear Regression

The normalization of the vehicle pass-by database begins with a linear regression of the data pairs consisting of the maximum A-weighted sound level versus the logarithm (base 10) of speed. This regression analysis is performed individually for each vehicle category, from each microphone location, at each measurement site.

The standard ISO 118149 makes note that speed is only one factor determining vehicle sound emissions. The note under Clause 9.1 says this may occur, “Particularly for heavy vehicles and for small speed ranges.” In this study, most of the linear regressions correlate fairly well, but many lower frequencies exhibit a low correlation, or even a negative slope to the linear regression. but the note continues, “This does not preclude the calculated regression from being used for compensating as much as possible for speed influence.”

A linear regression analysis of sound pressure levels on speed was made using data pairs for each vehicle pass-by. A regression line was fit to the data points for each separate vehicle category, using the least squares method.

Vehicle Sound Level at Reference Speed

The Vehicle Sound Level (using the symbol L_{veh}) is determined by calculating the value of the regression line at a given reference speed. Standard reference speeds are given in ISO 11819, Clause 9.2, Table 1. However, the standard reference speeds yielded spectral vehicle sound levels appeared very erratic, especially in the truck categories where the standard reference speed is several standard deviations away from the average measured speed, and in the 50 ft microphone position due to the lower sample sizes.

Clause 9.3 directs, “…the reference speed shall be within the range of plus-or-minus one standard deviation from the actually measured average speed for heavy vehicles and plus-or-minus one-and-a-half standard deviation for cars.” To that end, the particular reference speed of 115 km/h (71.5 mph) was used for cars instead of the standard reference speed of 110 km/h (68.4 mph), and the particular reference speed of 107 km/h (66.5 mph) was used for the truck categories instead of the standard reference speed of 85 km/h (52.8 mph). The analysis results appeared somewhat erratic with the standard reference speeds, but changing to the particular reference speeds showed more consistency in the results.

Using the particular, non-standard reference speeds limits the applicability of these results to comparison between each other, and cannot be compared to other SPB measurements without proper adjustment of the reference speeds.

The vehicle sound levels were not corrected for temperature. This is an optional procedure in ISO 11819, Clause 9.4, but the actual procedure has not yet been incorporated into the standard. The clause says, “A suitable method is at present still under consideration.”

Statistical Pass-By Index

The statistical pass-by index (SPBI) calculation was performed for the regional pavement measurements according to ISO 11819, Clause 9.5, and does use the standard reference weighting factors found in ISO 11819, Table 1. This is simply an average sound level of all three vehicle categories, assuming a standardized mix for the “High” Road Speed Category of 70.0% cars, 7.5% dual-axle heavy vehicles, and 22.5% multi-axle heavy vehicles. The SPBI was not calculated for the MnROAD test cells due to an insufficient sample size.

Reported Regression Parameters

The regression parameters are reported for each regression analysis. Explanations of the regression parameters are below.

Road speed category: is the road speed category according to ISO 11819, Clause 3.3. All road speed categories in this study are the “High” road speed category.

Reference speed: is the particular reference speed selected for the vehicle category in this study.

Number of vehicles: is the sample size of the data set.

Average speed: is the mean of the base-ten logarithm of speeds in kilometers per hour. The value for the average speed is converted from the logarithm to be reported in both kilometers per hour and miles per hour.

St. dev. of speed: is the standard deviation of the base-ten logarithm of speeds in kilometers per hour. The value for the standard deviation of speed is converted from the logarithm to be reported in both kilometers per hour and miles per hour.

Regr. line intercept: is the ordinate axis intercept value for the regression line of the data pairs for each band and for the overall A-weighted level.

Regr. line slope: is the slope of the regression line of the data pairs for each band and for the overall A-weighted level.

Correlation coefficient: is the correlation coefficient of data pairs for each band and for the overall A-weighted level.

Average sound level: is the mean sound level for each band and for the overall A-weighted level.

Std. dev. of sound level: is the standard deviation of sound levels for each band and for the overall A-weighted level.

Std. dev. of sound level residuals: is the standard deviation of residuals for each band and for the overall A-weighted level, where the residual is the difference of the actual ordinate value of a data pair, to the value of the regression line at the same abscissa value.

L_{veh} at ref. speed: is the vehicle sound level at the particular reference speed for each band and for the overall A-weighted level.

Chapter 7. Measurement Results

This chapter presents site observations of the character of the traffic noise, as well as aural observations during playback of the recorded traffic noise. The overall results of the measurement and analyses are presented as well.

Vehicle Noise Levels Observations

The most notable observation about all the measurements in general was that the further away the microphone position, the lower the quality of events. This was expected, since the geometry of the microphone and the lane of vehicle travel creates more favorable conditions at closer microphone positions. The 50’ microphone position had fewer qualifying pass-by events than the 25’ microphone position. And with the volume of traffic on these roads, the 100’ microphone position hardly had any qualifying pass-by events. Therefore recordings of the 100’ microphone position were not analyzed.

For the MnROAD test cell recordings, the 100’ microphone position was eliminated completely. But an added limitation was determined from the 50’ microphone position. The sound of adjacent test cells was more apparent when listening to the recordings due to the shorter lengths of pavement specimens. Additionally the reeds and cattails in the ditch had begun to dry out at that time in the fall, and because the microphone was in the middle of this vegetation the sound of rustling vegetation strongly interfered with measurements even in a very slight breeze. Therefore only the 25’ microphone position was analyzed for the MnROAD test cell recordings.

MnROAD Test Cell 7

Cell 7 was the innovative grind pavement test cell at MnROAD. Cell 7 was 500’ long, and adjacent to Cell 8. This pavement was measured concurrently with Cell 8 and Cell 97. Then it was also measured concurrently with Cell 4. The MnROAD test cell recordings all occurred on Saturday, November 7, 2009.

The initial position of the microphones was in the middle of the 500’ long cell. Unfortunately, there were circular openings at the same point of the test cell. Some vehicles passed over these openings and caused a loud impulsive sound. These sounds interfered with the measurement of the maximum pass-by level. The first hour of recording needed to be discarded due to this interference. After the first hour the microphone was relocated approximately 75’ away from the tubes. The result was enough separation in time that the impulse could be distinguishable from the maximum pass-by level, and postprocessed to eliminate the impulse by micro-fades on either side of the impulse. The result was the time-trace of the pass-by looked perfectly normal, except for a temporary interruption in the trace on the receding side for a fraction of a second. The maximum spectrum stopped changing before the point where this interruption occurred, which indicates that this processing method did not apparently affect the measurement result.

Another observation about these holes in the pavement is that they may be connected by underground tubes to other holes in the pavement. This conclusion is due to an infrequent observation of a secondary impulse sound. When a solitary car passes followed by a short lull in traffic the noise level was sometimes low enough that a second impulse through the tubes was barely audible, as if the solitary car passed over the far end of a tube and the impulse sound came out the near end. This secondary impulse was usually at or below the typical background noise level, and was only audible during very quiet lulls. Therefore the assumption for this Study is that the secondary impulse does not affect the maximum pass-by levels. However this cannot be assured with certainty without a separate investigation.

Another observation during postprocessing was that the pavement noise from the cell following Cell 7 was sometimes distinguishable from the cell 7 noise. This manifested in two ways. The first indication is a subtle change in tone when the vehicle passes the transition between the cells. This was only distinguishable for solitary pass-by events and a following lull in traffic. The second indication was a change in slope of the sound of the receding vehicle. As the vehicle passed the measurement point, the slope of the receding vehicle noise was fairly steep. But when the vehicle passed the transition between Cell 7 and the next cell, the slope became shallower. This suggests that the following cell produced more tire-pavement noise than Cell 7. But because the pass-by sound level trace did not exhibit an increase in level after the transition, any traffic present on the adjacent cell would affect the maximum noise level on Cell 7 only minimally. The exact extent of the influence was not part of the Study, but is noted here for the record.

The recording of Cell 7 which was concurrent with Cell 4 was not analyzed as part of this study. But the recording was retained for potential future measurement, data reduction and analysis.

MnROAD Test Cell 8

Cell 8 was the conventional grind pavement test cell at MnROAD. Cell 8 was 500’ long, and adjacent to Cell 7. This pavement was measured concurrently with Cell 7 and Cell 97. The MnROAD test cell recordings all occurred on Saturday, November 7, 2009.There were not any notable observations about the traffic noise on this test cell.

MnROAD Test Cell 97

Cell 97 was the transverse-tined pavement test cell at MnROAD. Cell 97 was less than 500’ long, and was adjacent to other transverse-tined pavement test cells, not included in this study. This pavement was measured concurrently with Cell 7 and Cell 8. The MnROAD test cell recordings all occurred on Saturday, November 7, 2009.

The most notable observation about this pavement was that the noise of the vehicles passing over the pavement control joints seemed higher than the noise of the tires on the pavement. It is likely that this SPB measurement reflects more of the control-joint noise than the pavement noise.

MnROAD Test Cell 4

Cell 4 was the Supepave pavement test cell at MnROAD. This pavement was measured concurrently with Cell 7. The MnROAD test cell recordings all occurred on Saturday, November 7, 2009.The recording of Cell 4 was not analyzed as part of this study. But the recording was retained for potential future measurement, data reduction and analysis.

Regional Control Pavement Specimen

This pavement was selected as the same material, age, and original finish as the innovative grind pavement specimen, but without the grind finish. The control pavement specimen recording occurred on Wednesday, September 02, 2009. There were not any notable observations about the traffic noise at this measurement site.

Regional Innovative Grind Pavement Specimen

This pavement is the 1,000’ long test section of innovative grind finish provided specifically for this study. The innovative grind pavement specimen recording occurred on Tuesday, August 18, 2009

When listening on headphones to the 50’ microphone position, a low-frequency rumble of truck engines was the first audible indications of approaching trucks. The low-frequency rumble developed well before the appearance of the truck, and even before any other sound of the truck. It also remained long after the truck had passed. This rumble appears in the spectral graphs of the 50’ microphone position as an apparent boost to the 80 Hz band. Interestingly there is also an apparent cut to the 125 Hz band. The lack of this rumble in the 25’ microphone position suggests that this effect may be a result of the measurement site, and is not solely attributable to the vehicle noise or tire-pavement noise.

SPB Analysis Results

The following tables and graphs show the Vehicle Sound Levels at the reference speeds. These graphs are a result of a regression calculation in each 1/3 octave band, and the tables show a regression calculation of each vehicle’s overall A-weighted Vehicle Sound Levels at reference speeds. The results reflect the particular reference speed used for this measurement, instead of the standard reference speed. The number of vehicles is the sample size for the data set. The regression parameters for the 1/3 octave band results are listed in Appendix C.

Refer to the topic heading of Data Analysis in Chapter 6 for explanations of the regression parameters. Decibel values are reported in each 1/3 octave-band as linear-weighted or unweighted decibels (dBL) and are reported for the overall sound level as A-weighted decibels (dBA). The results reflect the particular reference speed used for this measurement, instead of the standard reference speed.

Because there were only two dual-axle heavy vehicles (vehicle category 2a), for the MnROAD test cells, the regression analysis is omitted from this data set. But these two vehicles are included in the total heavy vehicle regression analysis (total for category 2 vehicles).

Table 7.1 Regression data for pavement cell 7 (innovative grind) at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	67.0	NA	-79.3	5.3
Regr. line slope	6.7	NA	83.6	41.6
Correlation coefficient	0.08	NA	0.86	0.33
Average sound level (dB)	80.9	88.6	90.6	90.2
Std. dev. of sound level (dB)	2.3	4.6	2.0	2.4
Std. dev. of sound level residuals (dB)	2.3	NA	1.0	0.9
L_{veh} (at ref. speed)	80.9	NA	90.4	89.8

* Value converted from the logarithm of speed.

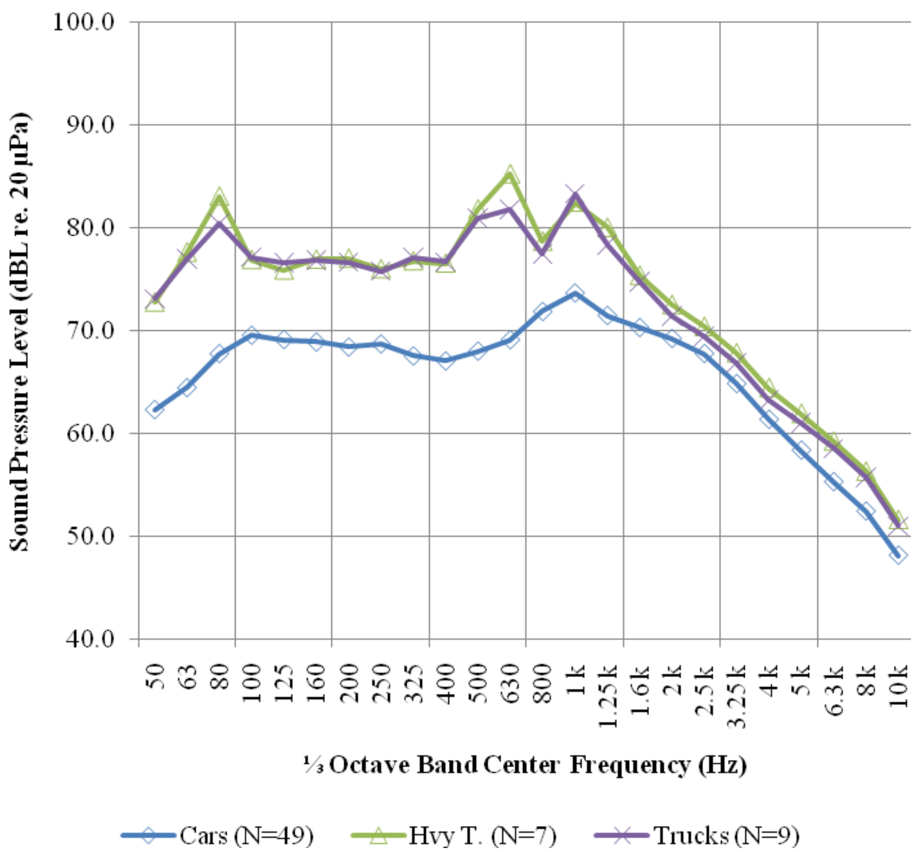

Figure 7.1. L_{veh} spectrum (at ref. speed) pavement cell 7 (innovative grind) at 25 ft

Table 7.2. Regression data for pavement cell 8 (conventional grind) at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	41.6	NA	-211.5	-146.5
Regr. line slope	20.2	NA	148.7	116.1
Correlation coefficient	0.32	NA	0.69	0.57
Average sound level (dB)	83.5	88.2	90.5	90.0
Std. dev. of sound level (dB)	1.8	2.0	4.3	3.8
Std. dev. of sound level residuals (dB)	1.7	NA	3.1	2.7
L_{veh} (at ref. speed)	83.3	NA	90.2	89.0

* Value converted from the logarithm of speed.

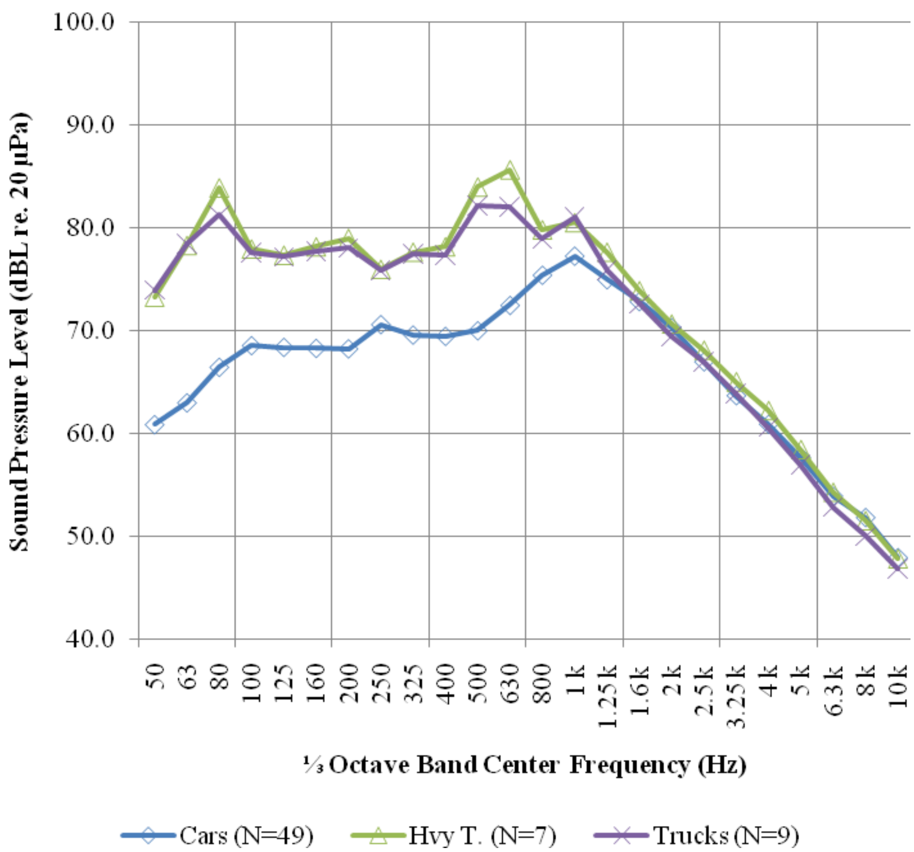

Figure 7.2. L_{veh} spectrum (at ref. speed) pavement cell 8 (conventional grind) at 25 ft

Table 7.3. Regression data for pavement cell 97 (transverse tine) at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	57.3	NA	134.2	130.7
Regr. line slope	15.5	NA	-19.0	-17.6
Correlation coefficient	0.25	NA	-0.30	-0.30
Average sound level (dB)	89.4	91.8	95.7	94.8
Std. dev. of sound level (dB)	1.8	0.2	1.3	1.1
Std. dev. of sound level residuals (dB)	1.8	NA	1.2	1.0
L_{veh} (at ref. speed)	89.2	NA	95.8	95.0

* Value converted from the logarithm of speed.

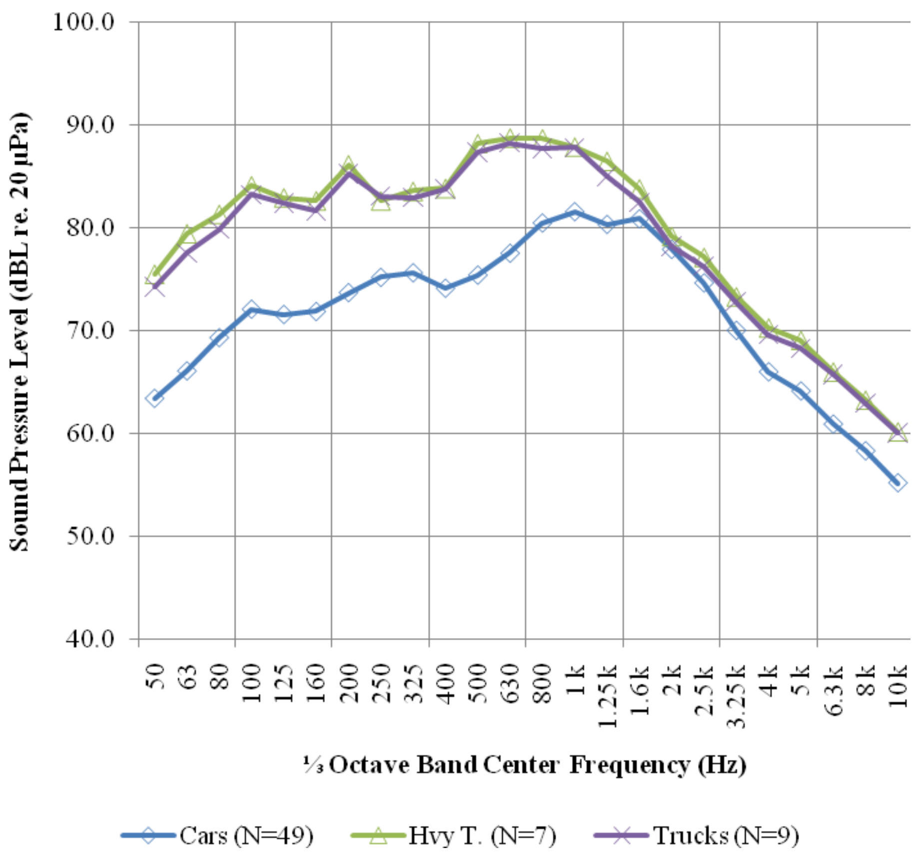

Figure 7.3. L_{veh} spectrum (at ref. speed) pavement cell 97 (transverse tine) at 25 ft

Table 7.4. Regression data for control pavement (burlap drag) at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	104	25	52	77
Average speed* (km/h)	115.2	105.7	107.6	107.0
St. dev. of speed* (km/h)	1.1	1.1	1.1	1.1
Regr. line intercept	50.1	-1.0	10.6	4.8
Regr. line slope	17.2	44.9	41.1	43.4
Correlation coefficient	0.24	0.58	0.44	0.51
Average sound level (dB)	85.6	89.9	94.2	92.8
Std. dev. of sound level (dB)	1.9	3.0	2.1	2.4
Std. dev. of sound level residuals (dB)	1.9	2.5	1.9	2.1
L_{veh} (at ref. speed)	85.6	90.1	94.1	92.8

* Value converted from the logarithm of speed.

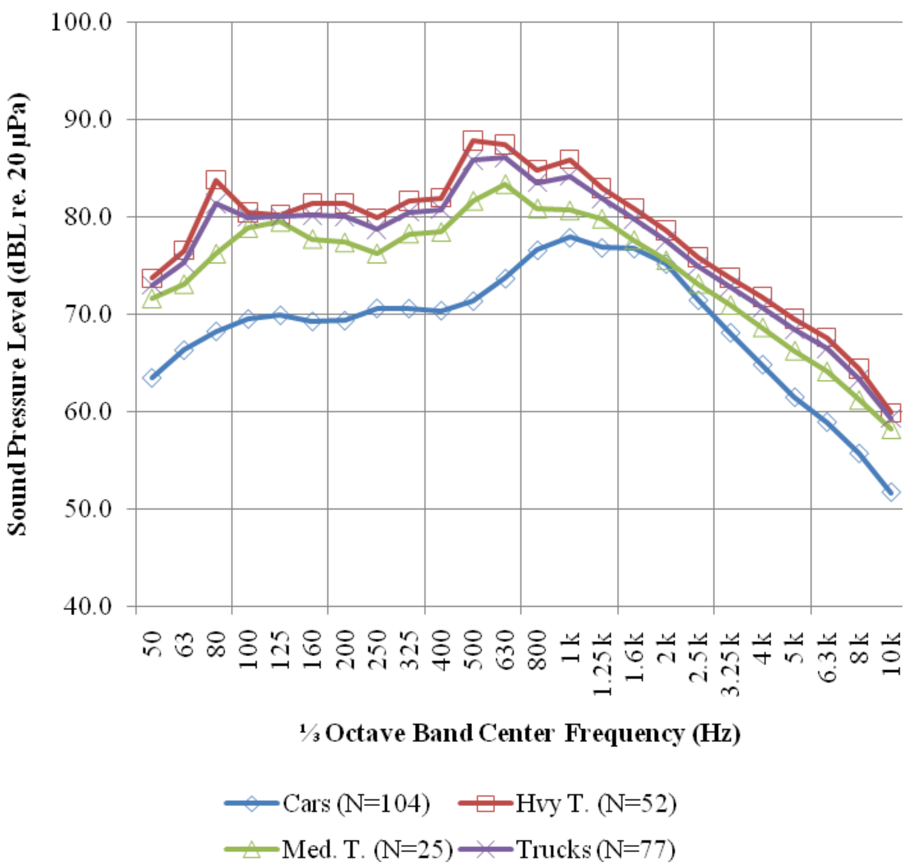

Figure 7.4. L_{veh} spectrum (at ref. speed) for control pavement (burlap drag) at 25 ft

Table 7.5. Regression data for control pavement (burlap drag) at 50 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	59	14	45	59
Average speed* (km/h)	115.2	108.3	107.6	107.8
St. dev. of speed* (km/h)	1.1	1.1	1.1	1.1
Regr. line intercept	35.5	5.0	10.7	9.2
Regr. line slope	21.3	38.5	37.8	38.0
Correlation coefficient	0.32	0.38	0.43	0.41
Average sound level (dB)	79.4	83.4	87.5	86.5
Std. dev. of sound level (dB)	2.0	3.2	2.0	2.3
Std. dev. of sound level residuals (dB)	1.9	3.0	1.8	2.1
L_{veh} (at ref. speed)	79.4	83.2	87.4	86.4

* Value converted from the logarithm of speed.

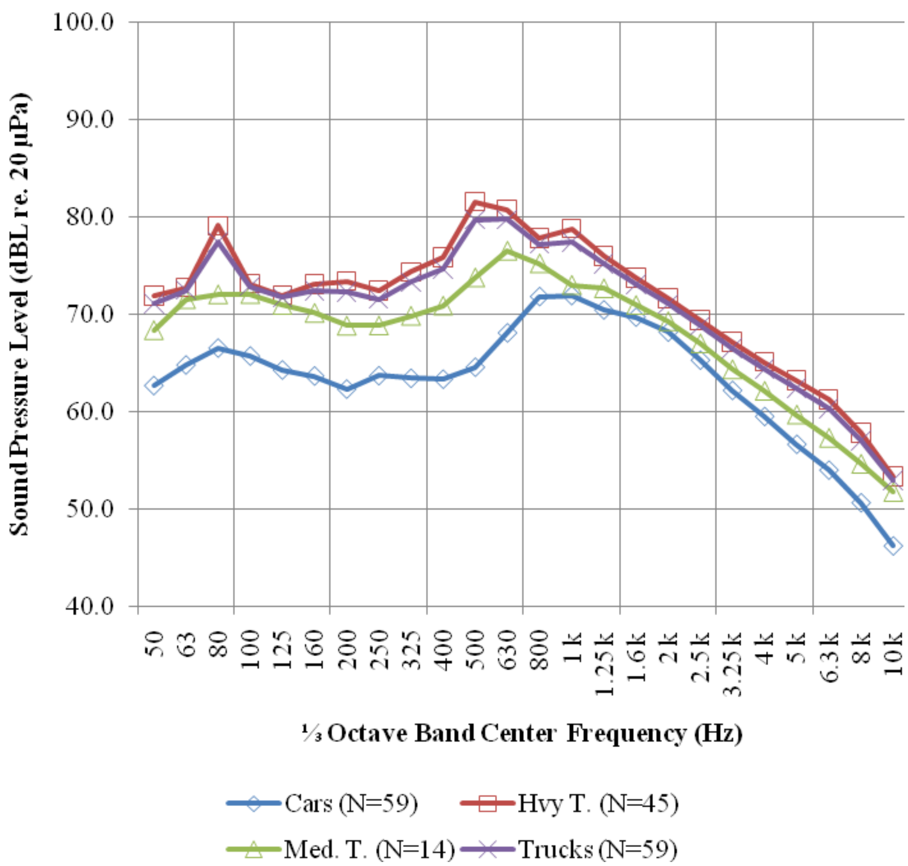

Figure 7.5. L_{veh} spectrum (at ref. speed) for control pavement (burlap drag) at 50 ft

Table 7.6. Regression data for subject pavement (innovative grind) at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	101	27	52	79
Average speed* (km/h)	115.1	107.7	106.3	106.8
St. dev. of speed* (km/h)	1.1	1.1	1.1	1.1
Regr. line intercept	74.6	45.7	-15.5	2.8
Regr. line slope	4.1	21.1	53.5	43.7
Correlation coefficient	0.05	0.17	0.49	0.38
Average sound level (dB)	83.1	88.7	92.8	91.4
Std. dev. of sound level (dB)	2.6	3.1	2.9	2.9
Std. dev. of sound level residuals (dB)	2.6	3.1	2.5	2.7
L_{veh} (at ref. speed)	83.1	88.6	92.9	91.4

* Value converted from the logarithm of speed.

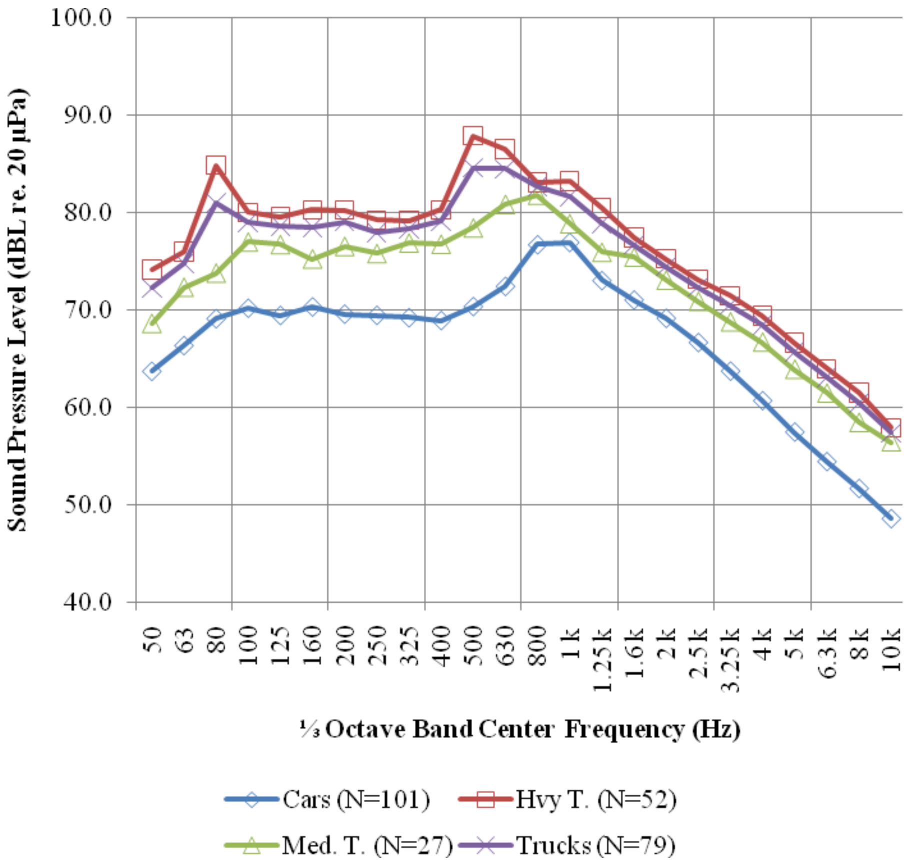

Figure 7.6. L_{veh} spectrum (at ref. speed) for subject pavement (innovative grind) at 25 ft

Table 7.7. Regression data for subject pavement (innovative grind) at 50 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	32	11	35	46
Average speed* (km/h)	115.8	107.6	107.1	107.2
St. dev. of speed* (km/h)	1.1	1.0	1.1	1.1
Regr. line intercept	83.3	101.3	-38.8	-22.0
Regr. line slope	-2.6	-8.6	61.5	52.9
Correlation coefficient	-0.02	-0.05	0.57	0.46
Average sound level (dB)	77.9	83.7	86.0	85.5
Std. dev. of sound level (dB)	2.7	2.9	2.7	2.7
Std. dev. of sound level residuals (dB)	2.7	2.9	2.2	2.4
L_{veh} (at ref. speed)	77.9	83.8	86.0	85.4

* Value converted from the logarithm of speed.

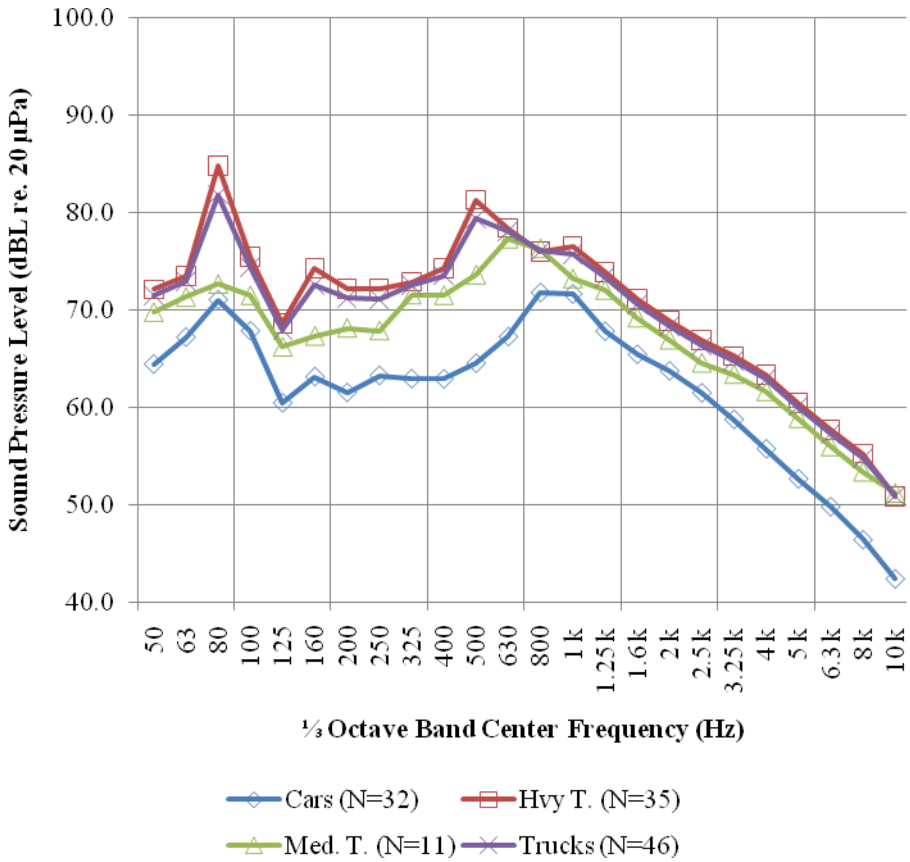

Figure 7.7. L_{veh} spectrum (at ref. speed) for subject pavement (innovative grind) at 50 ft

SPB Analysis of Paired Observations

The sample sizes of individual pavement cells at MnROAD are all much smaller than prescribed by ISO11819. So the confidence interval of the MnROAD test cells can be expected to be larger than the confidence intervals given in ISO 11819. However, these sample sets are all identical vehicles traveling at nearly identical speeds. Paired observations yield tighter confidence intervals than a comparison of means from two distinct sample sets. The advantage of paired observations is mentioned in ISO 11819 but the expected errors are not identified. The differences between the MnROAD pavement cell measurements may have less uncertainty than the uncertainty of a sample set of the same size with independent observations.

The difference in such matched sample sets can be analyzed by paired observations. The following tables and graphs reflect the same analyses performed on the difference between paired observations. The differences are evaluated to generate the sample set in the following manner:

- **Cell 7 vs. Cell 8**: is the level of the vehicle at cell 7 subtracted from the level of the same vehicle at cell 8, so positive values indicate that it is louder at cell 8 (conventional grind) where negative values indicate that it is louder at cell 7 (innovative grind).

- **Cell 7 vs. Cell 97**: is the level of the vehicle at cell 7 subtracted from the level of the same vehicle at cell 97, so positive values indicate that it is louder at cell 97 (transverse tine) where negative values indicate that it is louder at cell 7 (innovative grind).

- **Cell 8 vs. Cell 97**: is the level of the vehicle at cell 8 subtracted from the level of the same vehicle at cell 97, so positive values indicate that it is louder at cell 97 (transverse tine) where negative values indicate that it is louder at cell 8 (conventional grind).

The following tables and graphs show the differences in Vehicle Sound Levels at the reference speeds. These graphs are a result of a regression calculation in each 1/3 octave band, and the tables show a regression calculation of each vehicle's overall A-weighted levels. The number of vehicles is the sample size for the data set. The regression parameters for the 1/3 octave band results are listed in Appendix D.

Refer to the topic heading of Data Analysis in Chapter 6 for explanations of the regression parameters. Decibel values are reported in each 1/3 octave-band as linear-weighted or unweighted decibels (dBL) and are reported for the overall sound level as A-weighted decibels (dBA). The results reflect the particular reference speed used for this measurement, instead of the standard reference speed.

Because there were only two dual-axle heavy vehicles (vehicle category 2a), the regression analysis is omitted from this data set. But these two vehicles are included in the total heavy vehicle regression analysis (total for category 2 vehicles).

Table 7.8. Regression data paired observations between cell 7 and cell 8 at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	-25.4	NA	-132.2	-151.8
Regr. line slope	13.5	NA	65.0	74.4
Correlation coefficient	0.26	NA	0.40	0.47
Average sound level (dB)	2.6	-0.4	-0.1	-0.2
Std. dev. of sound level (dB)	1.5	2.6	3.2	2.9
Std. dev. of sound level residuals (dB)	1.4	NA	3.0	2.6
L_{veh} (at ref. speed)	2.4	NA	-0.2	-0.8

* Value converted from the logarithm of speed.

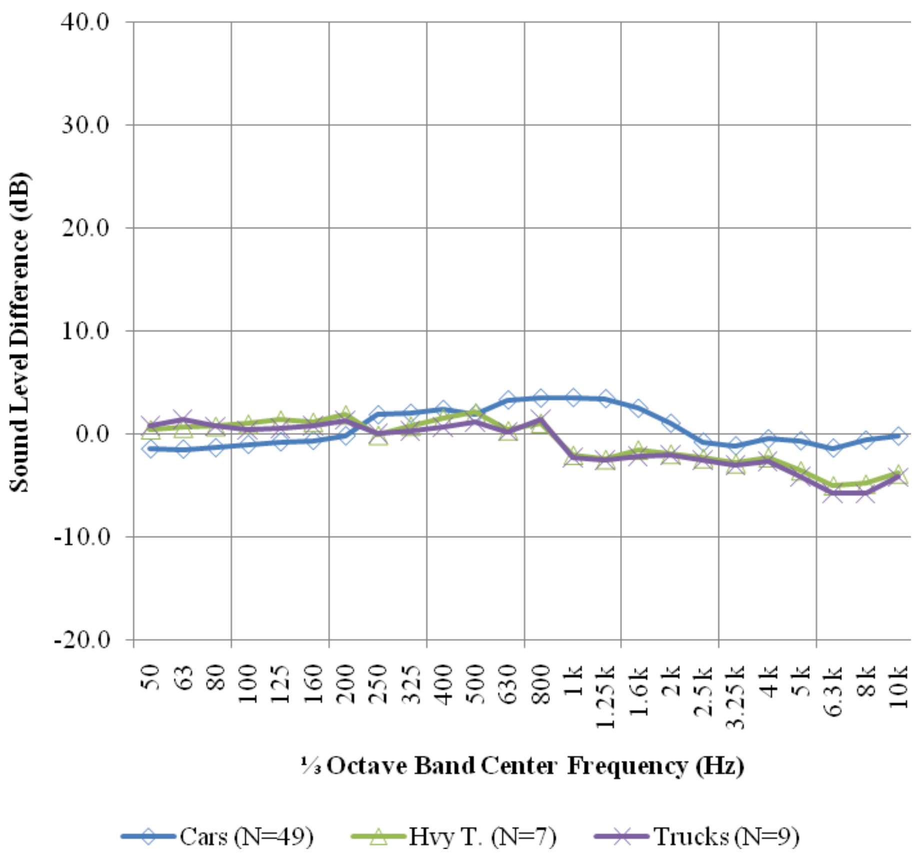

Figure 7.8. L_{veh} spectrum (at ref. speed) difference of cell 7 from cell 8 at 25 ft

Table 7.9. Regression data paired observations between cell 7 and cell 97 at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	-9.7	NA	213.6	125.4
Regr. line slope	8.8	NA	-102.6	-59.2
Correlation coefficient	0.11	NA	-0.82	-0.41
Average sound level (dB)	8.5	3.2	5.1	4.7
Std. dev. of sound level (dB)	2.3	4.4	2.5	2.7
Std. dev. of sound level residuals (dB)	2.3	NA	1.4	1.2
L_{veh} (at ref. speed)	8.3	NA	5.3	5.2

* Value converted from the logarithm of speed.

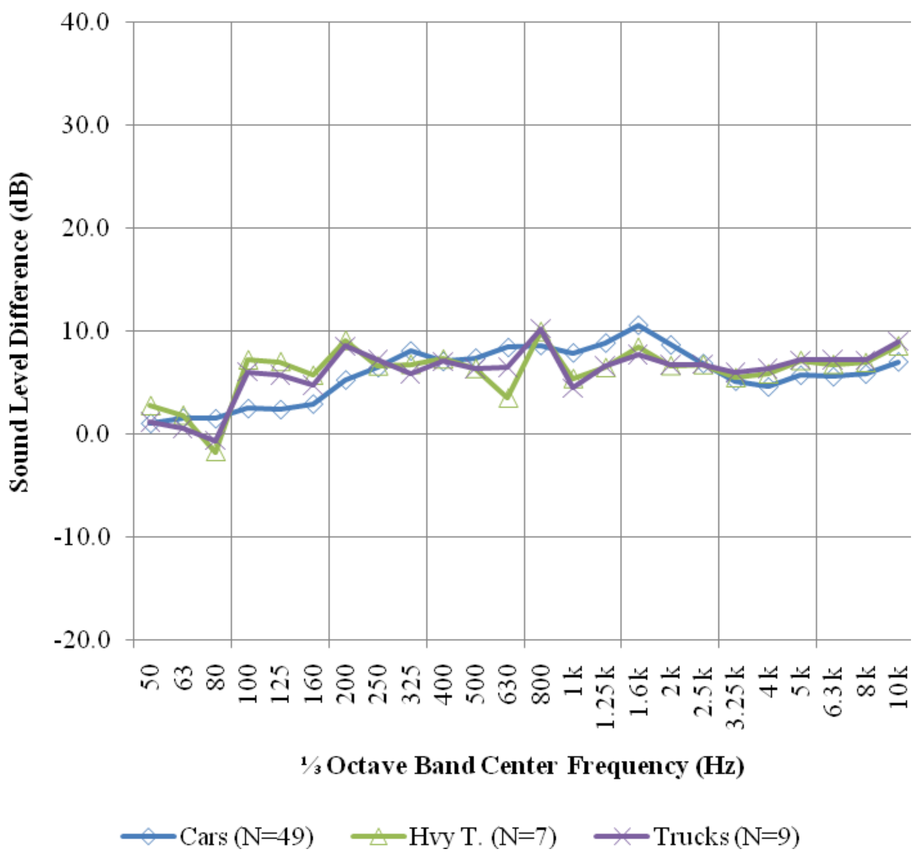

Figure 7.9. L_{veh} spectrum (at ref. speed) difference of cell 7 from cell 97 at 25 ft

Table 7.10. Regression data paired observations between cell 8 and cell 97 at 25 ft

Road speed category	High			
Regression Parameter:	Veh. cat 1 (cars)	Veh. cat 2a (dual-axle)	Veh. cat 2b (multi-axle)	Total for Veh. cat 2
Reference speed (km/h)	115	107	107	107
Number of vehicles	49	2	7	9
Average speed* (km/h)	118.3	114.6	107.5	109.1
St. dev. of speed* (km/h)	1.1	1.0	1.0	1.0
Regr. line intercept	15.7	NA	345.7	277.2
Regr. line slope	-4.7	NA	-167.6	-133.6
Correlation coefficient	-0.08	NA	-0.73	-0.61
Average sound level (dB)	5.9	3.6	5.2	4.8
Std. dev. of sound level (dB)	1.7	1.8	4.6	4.1
Std. dev. of sound level residuals (dB)	1.7	NA	3.2	2.7
L_{veh} (at ref. speed)	5.9	NA	5.6	6.0

* Value converted from the logarithm of speed.

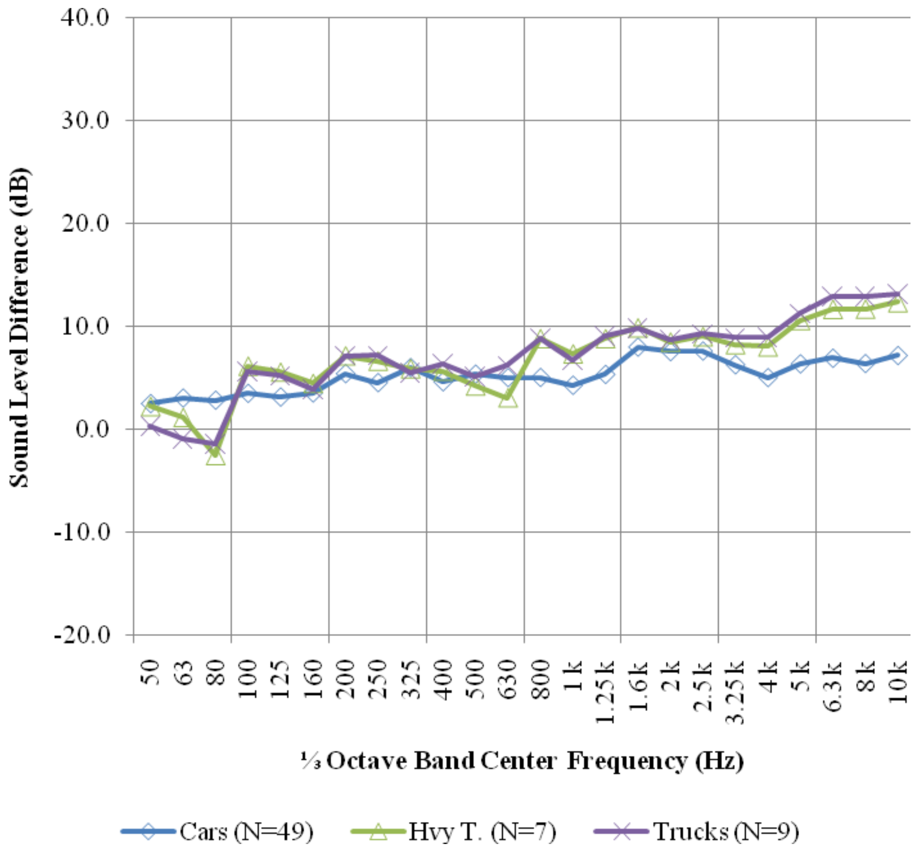

Figure 7.10. L_{veh} spectrum (at ref. speed) difference of cell 8 from cell 97 at 25 ft

Chapter 8. Critical Commentary

This chapter presents a discussion of the difference between the analysis results between pavement types. It also presents a discussion of the applicability of the Study.

Comparison of Pavement Types

The intent of this study is to compare the influence of tire-pavement noise on the overall noise emission of vehicles from all sources. This section addresses the differences of the noise emission levels at the selected measurement sites. As with all the analyses in this study, these results used the particular reference speed of 115 km/h (71.5 mph) for cars instead of the standard reference speed of 110 km/h (68.4 mph).

The 25’ microphone position is used throughout the comparisons in this chapter. A spectral comparison of the 50 ft microphone position at the regional measurement site is omitted from this commentary. It does not reveal any additional information beyond the comparison of 25 ft microphone positions. The 50 ft microphone position is only compared in terms of overall A-weighted level, because of one unusual result.

The only remarkable feature of the 50 ft microphone position occurs at the innovative grind pavement specimen, which exhibits an 80 Hz boost and 125 Hz cut. As discussed previously, this may be more of a characteristic of the particular environment of that microphone and not attributable to the vehicle noise.

MnROAD Test Cell Pavements

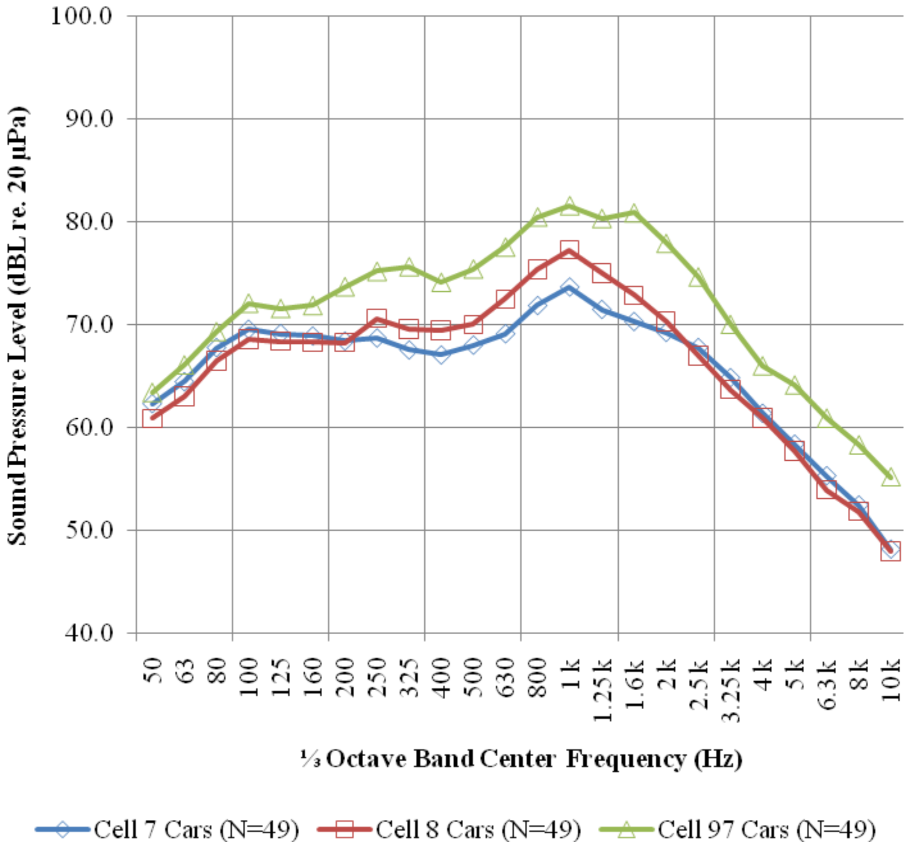

Figure 8.1. Vehicle category 1 (cars) comparison of MnROAD test cells

The figure above shows a comparison of category 1 (car) vehicle levels over MnROAD test cells. Cell 7 is the innovative grind pavement, Cell 8 is the conventional grind pavement, and Cell 97 is a transverse-tined pavement. These are the levels of the exact same vehicles passing over the pavements. The vehicle sound level is quietest for Cell 7, and loudest for Cell 97. Specifically, Cell 97 is higher in level in every band than either of the other cells. And Cell 8 is higher in level in the bands from 250 Hz to1.6 kHz. In some bands, cell 8 is higher in level than cell 7, but only nominally. Cell 8 and cell 7 can be considered roughly equivalent for vehicle noise level in those bands below 200 Hz and above 2.5 kHz. These results are favorable to the argument that the innovative grind is quieter.

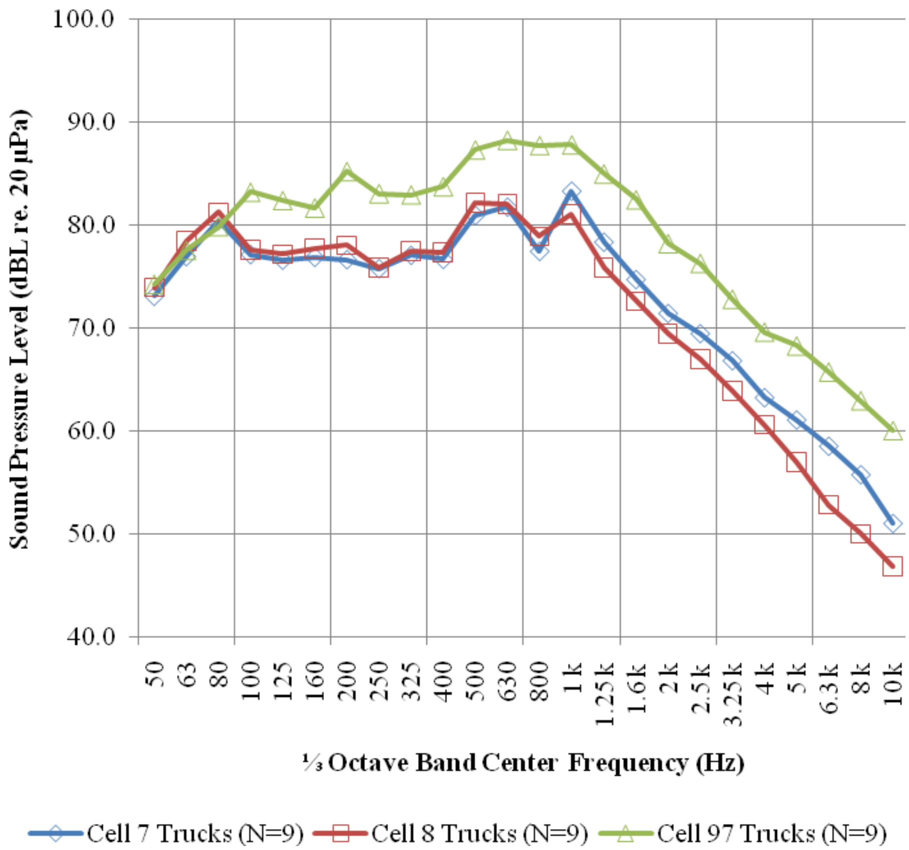

Figure 8.2. Vehicle category 2 (all trucks) comparison of MnROAD test cells

The figure above shows a comparison of category 2 (all trucks/heavy vehicles) sound levels over MnROAD test cells. As before, these are the levels of the exact same vehicles passing over the pavements, where Cell 7 is the innovative grind pavement, Cell 8 is the conventional grind pavement, and Cell 97 is a transverse-tined pavement. The vehicle sound level is quietest for Cell 8, and loudest for Cell 97. Specifically, Cell 97 is higher in level than either of the other cells in the bands above 100 Hz. Cell 8 and cell 7 can be considered roughly equivalent for vehicle noise level in those bands below 800 Hz. However, these results show that the conventional grind is quieter than the innovative grind for heavy vehicles in those bands above 1 kHz.

This result does not support the argument that the innovative grind is quieter. However this result comes from a very small sample size. In some bands the innovative grind SPB measurement is as much as 6 dB higher than the conventional grind SPB measurement. But the difference in overall A-weighted level is less than 1 dB, well within the uncertainty of expected random error for heavy vehicles. In fact, a paired t-Test of truck measurements at these two sites, by frequency-band, showed that all bands above 1 kHz had a p-value greater than 0.2. This indicates that the difference shown above is not statistically significant between Cell 7 and Cell 8. This issue merits further study before drawing any conclusions.

Regional Pavement Specimens

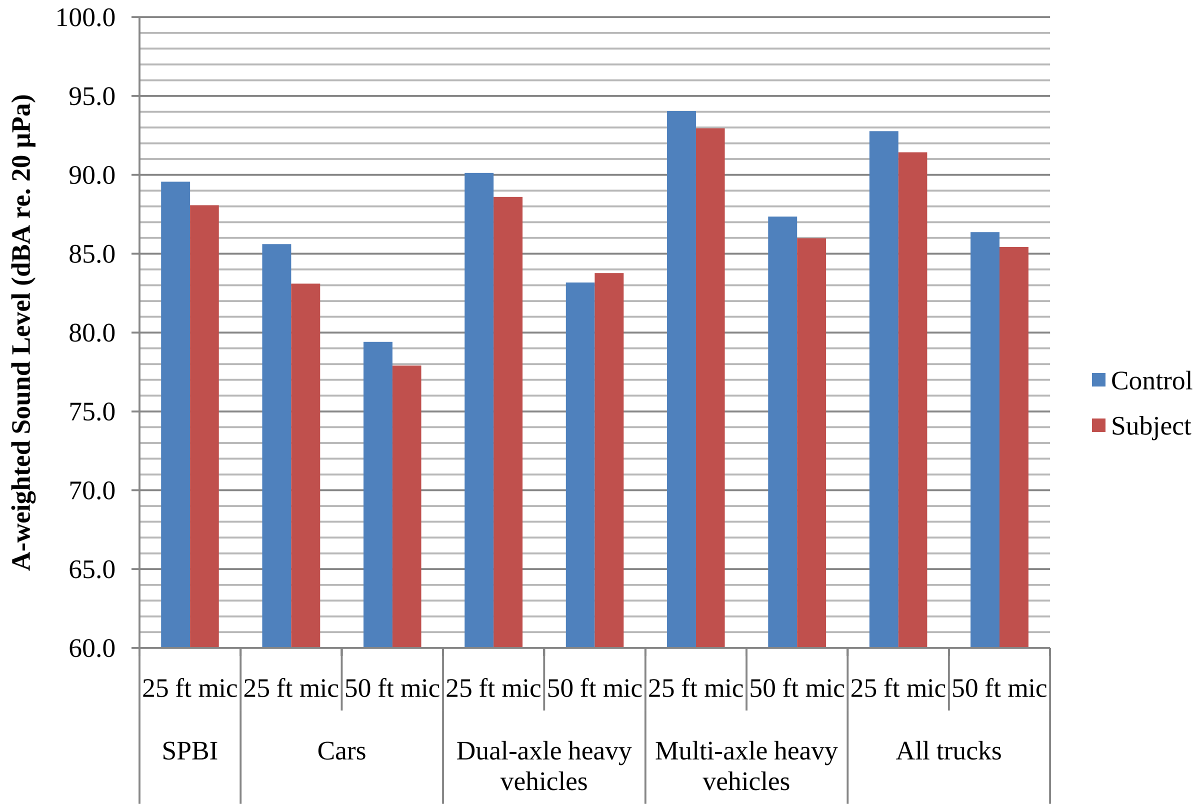

Figure 8.3. Summary of vehicle sound levels for the control and subject pavements

The figure above shows the Statistical Pass-by Index (SPBI), and the overall A-weighted Vehicle Sound Levels at reference speeds (L_{veh}). The results clearly show a reduction between 1 dBA and 3 dBA. The only exception is the 50 ft microphone and dual-axle heavy vehicles. It is a very small increase in noise level, and the two spectra of this vehicle category at this microphone position differ very little. With the one exception, these results are favorable to the argument that the innovative grind is quieter.

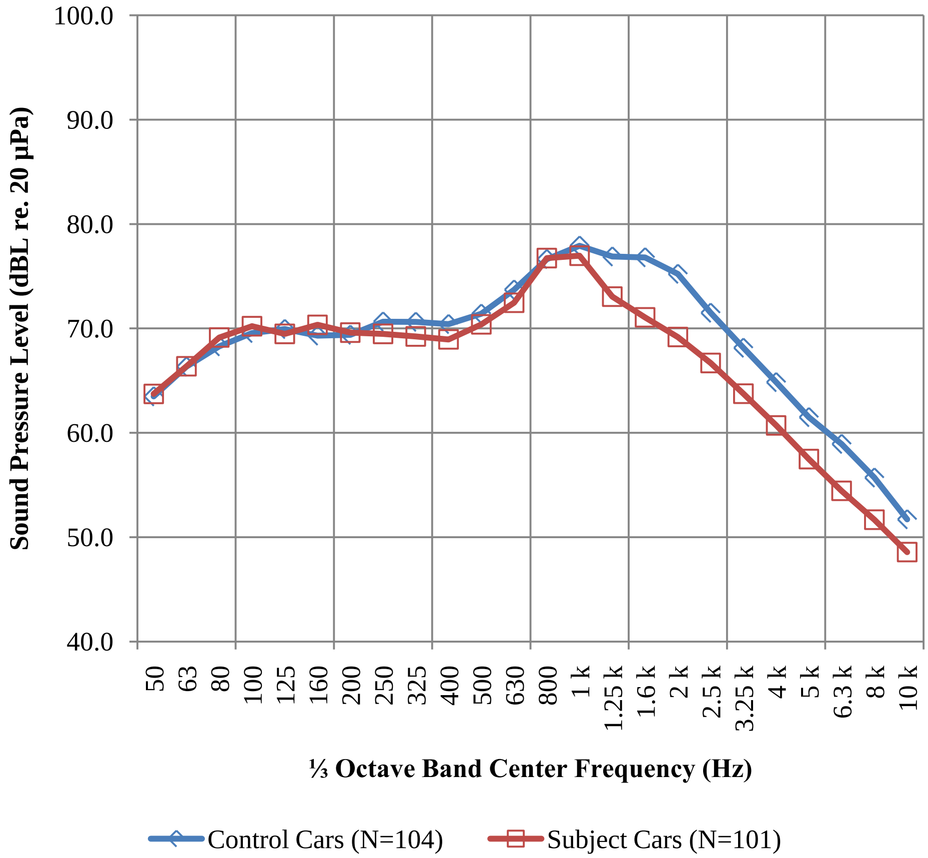

Figure 8.4. Vehicle category 1 (cars) control versus subject pavement

The figure above shows the difference between the spectral results of the regional pavement specimen analyses for vehicle category 1 (cars). The results align very closely in bands below 1 kHz, indicating agreement between the two measurement sites. There is a very clear reduction in vehicle sound levels in bands above 1 kHz for this vehicle category. This is favorable to the argument that the innovative grind is quieter.

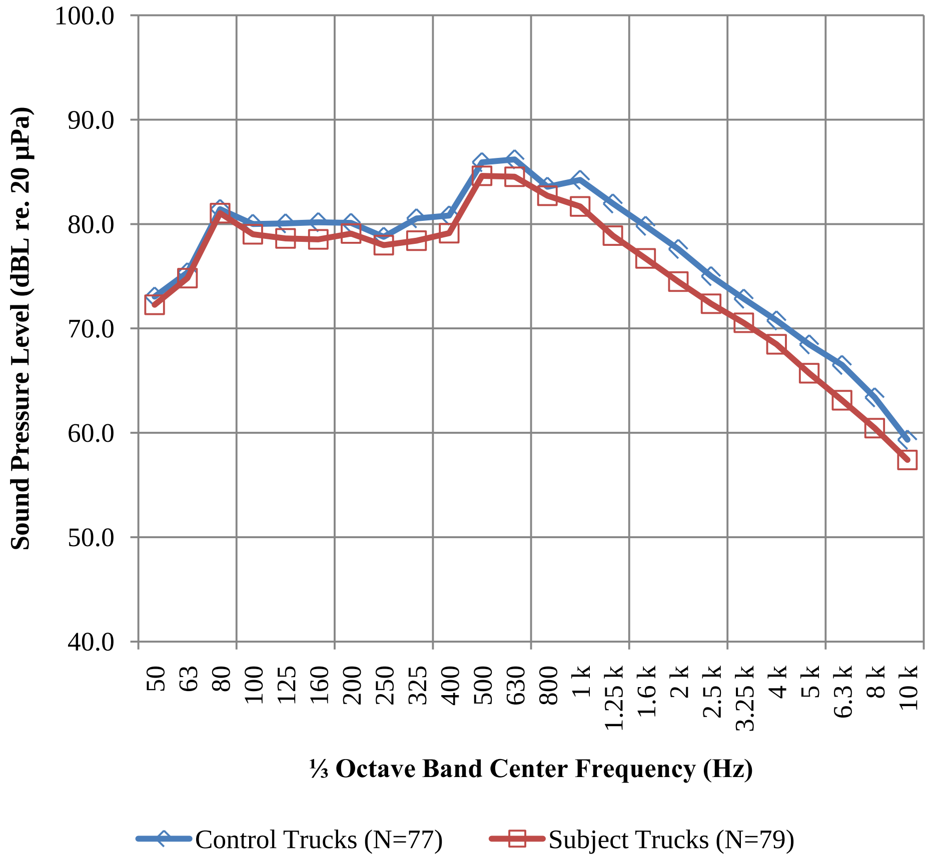

Figure 8.5. Vehicle category 2 (all heavy vehicles) control versus subject pavement

The spectral results for Vehicle Category 2a (dual-axle heavy vehicles) bear some resemblance to each other but are less consistent than the other two vehicle categories. This may be due to the smaller sample size of this data set. The spectral results for Vehicle Category 2b (multi-axle heavy vehicles) line up fairly well in bands below 1 kHz. There is a reduction in vehicle sound levels in bands above 1 kHz for this vehicle category, but the reductions for this category is not as large as for cars. The comparisons of these two subcategories are not shown, but the figure above is a comparison of the aggregate heavy vehicle category. It shows the reduction above 1 kHz discussed in regard to the multi-axle heavy vehicles. This is also favorable to the argument that the innovative grind is quieter.

Comparison of MnROAD Test Cells Versus Pavement Specimen

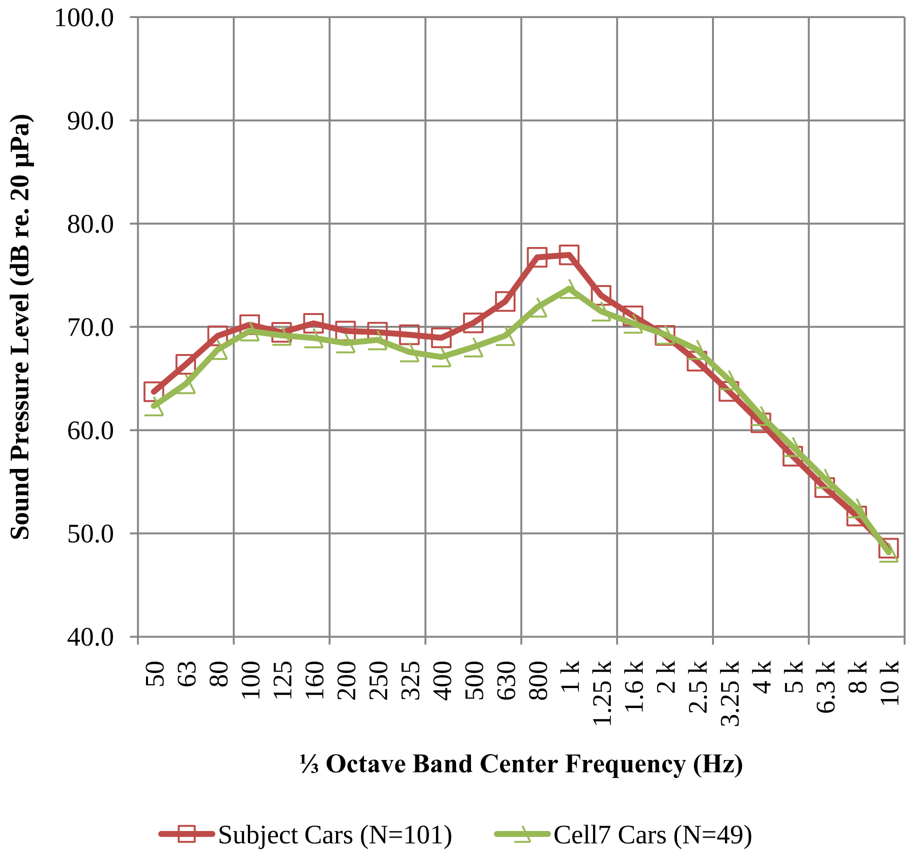

Figure 8.6. Vehicle category 1 (cars) MnROAD test cell 8 versus subject pavement on I-94

The figure above shows the measurement results for the regional innovative grind pavement specimen on I-94 and the MnROAD test cell 8, which is also the innovative grind pavement, are shown in the following graphs. They represent results from the 25 ft microphone position at each site, and for vehicle category 1 (cars). The vehicle sound level of the innovative grind test cell is lower than the innovative grind pavement specimen further north on I-94.

There is no guarantee than any two otherwise identical pavement surfaces at different times or locations will exhibit identical noise emission characteristics. Nonetheless, there are several reasonable possible explanations for this difference between the two specimens. The most likely reason is that the MnROAD test cell has been finished for longer than the regional pavement specimen on I-94. In general, concrete pavement surfaces get quieter with time. Additionally, the regional pavement specimen was finished so recently that there may have been grinding slurry residue remaining on the pavement, which will increase noise levels. (Izevbekhai, 2010)

Other factors which may contribute to the difference could include the specific vehicles in the sample set, their particular tires and general condition of the vehicle. The particular measurement sites could also affect the measurement. Every effort was made to eliminate interfering noises in the measurement, but there is no guarantee that other noise sources influenced the louder of the two measurement sets.

Uncertainty Considerations

During the course of this study, several considerations regarding measurement uncertainty were observed. These considerations may produce systematic errors to the measurement, not attributable to random errors. These systematic errors would only affect the uncertainty level of the results. The uncertainty levels identified in ISO 11819 is due to expected random errors for single-site measurements, based upon pre-normative research. The random errors found in that research were mainly attributable to variations in vehicles.

Vehicle Category Sample Sets

Due to the high volume of traffic, it was easier to capture a qualifying pass-by event if the vehicle was naturally louder. This excluded several vehicle pass-by events of extraordinarily quiet passenger cars, usually smaller and compact cars, and in some cases hybrid cars. By not including a representative proportion of these smaller and quieter cars, the sample set will have a bias towards noisier vehicles. It is reasonable to infer from this observation that the analysis results of the automobile sample are somewhat higher than would be for the automobile population.

The quantity of dual-axle heavy vehicles was very low, and those which were present were often within or causing vehicle bunches. Additionally, the sizes of the dual-axle heavy vehicles and their engine noise varied considerably. The smallest dual-axle heavy vehicles were small container trucks, not much larger than a four-wheel van. The largest dual-axle heavy vehicles were larger than some multi-axle heavy vehicles. This variation in vehicle noise combined with the small sample size contributed to a larger variation in the sound levels of dual-axle heavy vehicles.

The multi-axle heavy vehicles did not present any significant issues regarding capturing qualifying pass-by events. The noise levels of these vehicles are naturally higher, and were often solitary, without any other vehicles nearby.

Low-Frequency Data Quality

The assessment of event pass-by quality was determined by the A-weighted sound levels. Therefore, it is possible that not all frequency bands individually met the event quality criteria, even though the overall A-weighted level did meet the event quality criteria. The most likely frequency-bands which would not meet the quality criteria in these instances are the lower frequency-bands. The reason for this is in part due to the A-weighting level that was used to evaluate event quality emphasizes mid and high frequencies, and discounts low frequencies. Combine this reason with the fact that higher frequencies attenuate faster in the atmosphere than low frequencies, and there could be interfering noise from other vehicles in these low frequency-bands, hidden from view due to the A-weighting low-frequency discount.

To overcome this, the assessment of event quality would have to be performed so that each band was reviewed to see that it met the 6 dB rise and fall criteria, as well as the 10 dB over ambient noise level criterion. To perform this assessment in each band would require 24 discrete event quality assessments per event. Given that only one assessment was performed on each event using the overall A-weighted level, it is reasonable to assume that the bands from 200 Hz to 10 kHz met the event quality criteria, or were only nominally under. However, it is not possible to make the same assumption for the bands from 50 Hz to 160 Hz without a low-frequency event quality assessment.

At the innovative grind pavement specimen on I-94, this problem may be exacerbated. This is due to low-frequency rumble which was observed from heavy trucks in the 50 ft microphone location, and measured as an increase to the 80 Hz band. The observations and possible reasons for this were discussed above. But because the truck rumble may have been present during car pass-by events, it may also be partially responsible for the spike to the measured car levels.

Measurement Site Influence

As mentioned previously in more than one context, the 50 ft microphone location for the innovative grind pavement specimen on I-94 exhibited an apparent boost to the 80 Hz band, and a cut to the 125 Hz band. The most reasonable explanation is some characteristic of the measurement site geometry such as the ditch and ground profile, the road profile and curve, and perhaps the berm or other reflecting surfaces within a couple-hundred feet of the microphone. ISO 11819 describes a goal to have the microphones in an approximate “free field” environment, but the environment for this microphone position seems to fall short of that goal in these lower frequencies.

Additionally, and as discussed previously, the MnROAD test cells presented a couple of influences due to the measurement site. First were the holes in the pavement which create impulsive sounds when vehicles passed over. And second was the short length of the pavement test cells. A third interference was the noise of reeds at the 50-ft microphone position. The first influence was addressed by relocating the microphone and additional postprocessing. The other two influences from the measurement site were dealt with by discarding the 50’ microphone position. Despite this, there cannot be complete certainty that one or more of these interferences don’t still have some unseen or unheard influence on the measurement result.

Microphone Position

As noted previously, the nearest microphone position could capture more high-quality events than the further microphone position, simply due to geometry between the microphone and the traffic as it relates to sound propagation behavior. Additionally, many of the above uncertainty considerations would also be made worse when the microphone position is further from the traffic. In fact, there were so few usable events at the 100’ microphone position anywhere that it was discarded completely. And at the MnROAD test cells, the shorter lengths of pavement specimens were partially responsible for discarding the 50’ microphone position for those sites.

Chapter 9. Conclusion

The adopted SPB measurement method was to record video and a high-quality audio of all the traffic over several hours, along with a calibration reference level, and analyze the recorded traffic in the office. This method was successful in dealing with the extremely high volume of traffic on this portion of interstate. It was not without some drawbacks, most notably, capturing a large enough sample size of qualifying events in certain vehicle categories proved impossible with the single-day window of recording time. Furthermore, there were some potential systematic errors which could not be addressed with either the planned or the adopted measurement procedures. Measurements were discarded where these errors obviously interfered. A statistical assessment of the uncertainty was not part of this study, but qualitatively speaking these systematic errors should be minimal or at worst understate the actual differences between the pavement types.

Measurement results with 4-wheeled passenger cars showed the innovative grind was clearly quieter than the comparison pavement types. The qualitative term “Quieter” is taken to mean that there is a lower contribution of tire-pavement noise to the overall vehicle noise when traveling over that “quieter” pavement. In other words, the noise emission of an “average” vehicle is lower when traveling over a “quieter” pavement. Results of dual-axle and multi-axle heavy vehicles also showed the innovative grind was quieter than most other pavement surfaces, including the transverse tine pavement surface and the burlap drag pavement surface. But results were inconclusive due to a small heavy-vehicle sample size between the conventional grind and innovative grind pavement surfaces in terms of tire-pavement noise influence on overall traffic noise levels.

It must be noted therefore that OBSI captures the difference between the tire pavement interaction sources for various texture types but beyond the source, the higher frequency component of OBSI attenuate quickly and only a comparison of the lower frequency difference is made at a receiver at a reasonable distance from the source. Nevertheless the quieter pavements result in quieter overall noise.

Recommendation: The summation of OBSI over twelve third octave frequencies starting from 400-hz does not facilitate an evaluation of some relevant tire pavement generated low frequency sounds. Since the rate of decay due to surface absorption, diffraction and reflection is frequency dependent an OBSI definition over a broader range of frequencies will enhance adequate comparison between OBSI and SPB. The 3rd octave frequency should start from 100-hz. Nevertheless a deployment of the innovative grind as a noise reduction technology is recommended by this study.

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7. American Association of State and Highway Transportation Officials, 2008, 11 pages.

Appendix A Technical Descriptions of Pavement Specimens

Pavement Surface Overview

The following pavement surfaces were included in this study:

- *Innovative Grind*: The innovative grind pavement is located at MnROAD Cell 7 and at the regional subject pavement measurement site. This pavement surface is discussed below under the heading, “Diamond Ground Surfaces.”

- *Burlap Drag:* The burlap drag pavement is at the regional control pavement measurement site.

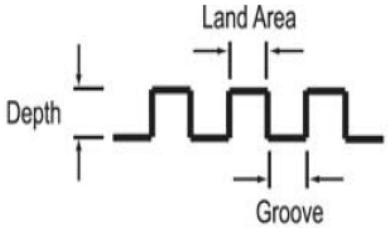
- *Transverse Tine:* The transverse tine pavement is located at MnROAD Cell 97.

- *Conventional Grind:* The conventional grind pavement is located at MnROAD Cell 8. This pavement surface is discussed below under the heading, “Diamond Ground Surfaces.”

- *Superpave*: The Superpave pavement is located at MnROAD Cell 4. The traffic was recorded for this pavement, but data were not measured and reduced from the recordings.

Diamond Ground Surfaces

Diamond grinding creates grooves and land areas according to the setting of the spacers and blades of the diamond grinding equipment. The land area is the riding surface of the configuration and the groove is the rectangular indentation between land areas. The groove-land area configuration is therefore a repeating pattern through the width of the pavement. The wavelength is the sum of the widths of a groove and a land area. The groove depth is the elevation difference between the land area and the bottom of the groove. By changing the blade and spacer stacking on the shaft, surfaces with different groove and land area configurations can be created. A generic sketch of a typical grinding configuration is shown in **Error! Reference source not found.**, with photographs of diamond grinding surfaces.



a) General Configuration

b) Conventional Grind Cell 8

c)Innovative Grind Cell 7

d)Ultimate Grind Cell (Rotated)

Figure A.1. General Diamond Grinding Configuration Nomenclature
and three Grinding Configurations

Four types of diamond grinding surfaces were included in this study. A conventionally diamond ground surface is located on the MnROAD mainline cell 8 (photograph 'b' of **Error! Reference source not found.**). This is the traditional grinding configuration, commonly used in the freeway system. Its configuration is shown in Table A-1. The second section is located in cell 7 and has an innovatively ground texture (photograph 'c' of **Error! Reference source not found.**). This is a new configuration, designed for noise reduction. In this grinding, the pre-existing transverse tine was not obliterated by the new grinding texture. The depth of grinding performed was only sufficient to simulate a partial grind texture.. To achieve this configuration, the land area of an innovative grinding configuration had been further corrugated to enhance friction.

Table A.1. Configurations of the Diamond-ground Surfaces Included in this Study

Grinding Type	Location	Configuration Dimensions (Inches)			
		Land Width	Groove Width	Groove Depth	Wave Length
Conventional	Cells 8	0.129	0.125	0.047	0.254
Innovative	Cell 7	0.364	0.136	0.067	0.500

Appendix B Traceable Instrumentation List

This appendix lists the instrumentation which receives traceable calibration.

Item	Brand	Model	S/N
Handheld Calibrator	Larson Davis	CAL200	3722
Handheld Calibrator	Larson Davis	CAL200	4467
½" Free-field 200V Bias Microphone	Larson Davis	2541	4185
½" Free-field 200V Bias Microphone	Larson Davis	2541	4652
½" Free-field 200V Bias Microphone	Larson Davis	2541	7490
½" Free-field 200V Bias Microphone	Larson Davis	2541	7546
½" Free-field Prepolarized Microphone	PCB Piezotronics	377B02	112593
½" Free-field 200V Bias Microphone	PCB Piezotronics	377B41	1004
Preamplifier for LD 820	Larson Davis	PRM828	2130
Preamplifier for LD 820	Larson Davis	PRM828	2158
Preamplifier for LD 820	Larson Davis	PRM828	2746
Preamplifier	Larson Davis	PRM900B	3519
Preamplifier	Larson Davis	PRM900C	0845
Preamplifier	Larson Davis	PRM902	2618
Preamplifier	Larson Davis	PRM902	3380
Single-Chanel Sound Level Meter [1]	Larson Davis	820	1278
Single-Chanel Sound Level Meter [1]	Larson Davis	820	1413
Single-Chanel Sound Level Meter [1]	Larson Davis	820	1765
Single-Chanel Sound Level Meter [1]	Larson Davis	824	2636
Single-Chanel Sound Level Meter [1]	Larson Davis	824	3204
Dual-Chanel Sound Level Meter [1,2]	Larson Davis	2900B	0885

[1] Sound Level Meter used as microphone power supply; audio signal output to recording device.
[2] Sound Level Meter used as desktop analyzer system for audio playback; see text for calibration and playback methods.

Appendix C Sound Level and Speed Regression Data for Individual Measurement Sites

This appendix contains the sound level and speed regression data for each measurement set. Refer to the topic heading of Data Analysis in Chapter 6 for explanations of the regression parameters.

Decibel values are reported in each 1/3 octave-band as linear-weighted or unweighted decibels (dBL) and are reported for the overall sound level as A-weighted decibels (dBA). Speeds are reported in both kilometers per hour and miles per hour.

Table C.1. Sound Level and Speed Regression Data Pavement Cell 7 (innovative grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	49	
Average speed* (km/h [mph])	118.3	[73.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	73.63	64.43	105.66	73.78	49.98	24.29	37.96	37.17	33.06	71.44	44.01	33.21	96.35	51.93	19.37
Regr. line slope	-5.48	0.03	-18.38	-2.03	9.31	21.66	14.79	15.32	16.75	-2.11	11.66	17.44	-11.86	10.57	25.31
Correlation coefficient	-0.05	0.00	-0.14	-0.01	0.08	0.24	0.16	0.17	0.18	-0.02	0.09	0.12	-0.08	0.11	0.28
Average sound level (dBL)	62.3	64.5	67.6	69.6	69.3	69.2	68.6	68.9	67.8	67.1	68.2	69.4	71.8	73.8	71.8
Std. dev. of sound level (dBL)	3.3	3.4	3.9	4.5	3.6	2.7	2.7	2.6	2.8	2.7	3.9	4.2	4.1	2.7	2.6
Std. dev. of sound level residuals (dBL)	3.3	3.4	3.8	4.5	3.5	2.6	2.7	2.6	2.7	2.7	3.9	4.1	4.1	2.7	2.5
L_{veh} at ref. speed (dBL)	62.3	64.5	67.8	69.6	69.2	68.9	68.4	68.7	67.6	67.1	68.0	69.1	71.9	73.7	71.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
Regr. line intercept	98.56	89.31	75.89	39.69	13.33	14.19	16.93	7.19	6.42
Regr. line slope	-13.70	-9.72	-3.92	12.22	23.33	21.45	18.63	21.97	20.26
Correlation coefficient	-0.11	-0.10	-0.05	0.16	0.28	0.30	0.28	0.27	0.26
Average sound level (dBL)	70.2	69.2	67.8	65.0	61.7	58.7	55.6	52.7	48.4
Std. dev. of sound level (dBL)	3.5	2.7	2.1	2.2	2.4	2.1	2.0	2.4	2.2
Std. dev. of sound level residuals (dBL)	3.5	2.7	2.1	2.2	2.3	2.0	1.9	2.3	2.2
L_{veh} at ref. speed (dBL)	70.3	69.3	67.8	64.9	61.4	58.4	55.3	52.5	48.2

Regression parameter	Overall
Regr. line intercept	67.00
Regr. line slope	6.72
Correlation coefficient	0.08
Average sound level (dBA)	80.9
Std. dev. of sound level (dBA)	2.3
Std. dev. of sound level residuals (dBA)	2.3
L_{veh} at ref. speed (dBA)	80.9

Table C.2. Sound Level and Speed Regression Data Pavement Cell 7 (innovative grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	2	
Average speed* (km/h [mph])	114.6	[71.2]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	74.3	73.5	76.1	75.6	78.8	76.4	72.0	73.0	73.5	73.7	80.2	73.0	73.3	85.6	74.5
Std. dev. of sound level (dBL)	1.0	0.9	1.1	7.7	5.0	0.4	4.4	1.1	4.0	4.6	11.7	0.6	3.6	6.6	4.4
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	72.8	68.6	67.7	64.6	60.7	60.0	58.0	55.2	50.3	Average sound level (dBA)	88.6
Std. dev. of sound level (dBL)	2.9	3.3	5.2	5.2	4.0	2.6	3.4	2.5	1.1	Std. dev. of sound level (dBA)	4.6
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table C.3. Sound Level and Speed Regression Data Pavement Cell 7 (innovative grind) at MnROAD, measured Saturday, November 7, 2009 25’ microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	7	
Average speed* (km/h [mph])	107.5	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	51.26	157.73	-319.08	125.83	7.40	120.89	263.02	220.70	380.79	270.87	-339.03	-193.89	151.67	2.48	15.61
Regr. line slope	10.62	-39.46	198.18	-24.10	33.77	-21.65	-91.63	-71.28	-149.79	-95.74	207.39	137.56	-35.95	39.44	31.76
Correlation coefficient	0.09	-0.12	0.59	-0.28	0.21	-0.14	-0.73	-0.71	-0.57	-0.91	0.69	0.55	-0.45	0.26	0.19
Average sound level (dBL)	72.8	77.6	83.5	76.9	76.0	76.9	76.9	75.9	76.5	76.4	82.3	85.6	78.6	82.6	80.1
Std. dev. of sound level (dBL)	2.3	6.9	6.7	1.7	3.2	3.1	2.5	2.0	5.3	2.1	6.1	5.1	1.6	3.1	3.4
Std. dev. of sound level residuals (dBL)	2.3	6.8	5.4	1.7	3.1	3.1	1.7	1.4	4.3	0.9	4.4	4.2	1.4	3.0	3.4
L_{veh} at ref. speed (dBL)	72.8	77.7	83.1	76.9	75.9	77.0	77.1	76.0	76.8	76.6	81.9	85.3	78.7	82.5	80.1

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	121.25	65.54	60.29	76.11	15.57	-33.83	-29.30	-1.70	-32.76	Regr. line intercept	-79.31
Regr. line slope	-22.60	3.46	5.00	-4.06	24.10	47.21	43.65	28.61	41.59	Regr. line slope	83.65
Correlation coefficient	-0.29	0.08	0.10	-0.08	0.24	0.43	0.42	0.43	0.53	Correlation coefficient	0.86
Average sound level (dBL)	75.3	72.6	70.4	67.9	64.5	62.1	59.4	56.4	51.7	Average sound level (dBA)	90.6
Std. dev. of sound level (dBL)	1.6	0.8	1.0	1.0	2.0	2.2	2.1	1.3	1.6	Std. dev. of sound level (dBA)	2.0
Std. dev. of sound level residuals (dBL)	1.5	0.8	1.0	1.0	2.0	2.0	1.9	1.2	1.3	Std. dev. of sound level residuals (dBA)	1.0
L_{veh} at ref. speed (dBL)	75.4	72.6	70.4	67.9	64.5	62.0	59.3	56.4	51.6	L_{veh} at ref. speed (dBA)	90.4

Table C.4. Sound Level and Speed Regression Data Pavement Cell 7 (innovative grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	9	
Average speed* (km/h [mph])	109.1	[67.8]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	68.03	159.47	-254.37	226.22	86.24	110.33	299.29	217.52	396.72	309.50	-123.74	-152.70	91.29	105.38	-38.30
Regr. line slope	2.52	-40.64	165.02	-73.44	-4.73	-16.46	-109.68	-69.82	-157.48	-114.71	100.89	115.56	-6.79	-10.85	57.50
Correlation coefficient	0.02	-0.13	0.53	-0.44	-0.03	-0.11	-0.76	-0.73	-0.61	-0.87	0.28	0.49	-0.07	-0.06	0.32
Average sound level (dBL)	73.2	76.7	81.9	76.6	76.6	76.8	75.8	75.2	75.8	75.8	81.8	82.8	77.4	83.3	78.9
Std. dev. of sound level (dBL)	2.1	6.0	5.8	3.1	3.3	2.7	2.7	1.8	4.8	2.4	6.7	4.4	1.9	3.6	3.3
Std. dev. of sound level residuals (dBL)	2.0	5.9	4.7	1.4	2.7	2.7	1.5	1.2	3.8	0.8	3.8	3.7	1.3	2.6	2.9
L_{veh} at ref. speed (dBL)	73.1	77.0	80.5	77.2	76.7	76.9	76.7	75.8	77.1	76.7	81.0	81.8	77.5	83.4	78.4

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	74.70	19.46	-11.58	1.81	-34.02	-58.50	-65.50	-28.98	-38.13	Regr. line intercept	5.30
Regr. line slope	0.03	25.63	39.96	32.06	47.94	58.94	61.13	41.77	43.94	Regr. line slope	41.64
Correlation coefficient	0.00	0.34	0.37	0.29	0.40	0.51	0.53	0.54	0.57	Correlation coefficient	0.33
Average sound level (dBL)	74.8	71.7	69.8	67.1	63.7	61.6	59.1	56.1	51.4	Average sound level (dBA)	90.2
Std. dev. of sound level (dBL)	1.7	1.4	2.0	2.1	2.2	2.1	2.2	1.5	1.4	Std. dev. of sound level (dBA)	2.4
Std. dev. of sound level residuals (dBL)	1.3	0.7	0.8	0.9	1.7	1.7	1.6	1.0	1.2	Std. dev. of sound level residuals (dBA)	0.9
L_{veh} at ref. speed (dBL)	74.8	71.5	69.5	66.9	63.3	61.1	58.6	55.8	51.0	L_{veh} at ref. speed (dBA)	89.8

Table C.5. Sound Level and Speed Regression Data Pavement Cell 8 (conventional grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	49	
Average speed* (km/h [mph])	118.3	[73.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	52.26	45.72	63.92	54.50	24.93	55.80	43.92	67.82	9.33	55.65	21.07	31.77	81.45	40.12	-7.00
Regr. line slope	4.20	8.40	1.25	6.85	21.11	6.08	11.83	1.37	29.26	6.73	23.77	19.77	-2.91	18.04	39.80
Correlation coefficient	0.04	0.08	0.01	0.04	0.18	0.06	0.10	0.02	0.29	0.08	0.21	0.19	-0.03	0.23	0.42
Average sound level (dBL)	61.0	63.1	66.5	68.7	68.7	68.4	68.4	70.7	70.0	69.6	70.3	72.8	75.4	77.5	75.5
Std. dev. of sound level (dBL)	3.2	3.0	3.3	4.7	3.4	2.8	3.4	2.3	2.9	2.5	3.3	3.1	2.7	2.3	2.8
Std. dev. of sound level residuals (dBL)	3.2	3.0	3.3	4.7	3.3	2.7	3.4	2.3	2.8	2.5	3.2	3.0	2.7	2.2	2.5
L_{veh} at ref. speed (dBL)	60.9	63.0	66.5	68.6	68.4	68.3	68.3	70.6	69.6	69.5	70.0	72.5	75.5	77.3	75.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	36.77	45.91	44.20	46.29	38.81	35.89	40.58	44.94	30.21	Regr. line intercept	41.63
Regr. line slope	17.53	11.87	11.08	8.47	10.75	10.61	6.50	3.37	8.63	Regr. line slope	20.21
Correlation coefficient	0.18	0.14	0.16	0.15	0.19	0.15	0.09	0.04	0.09	Correlation coefficient	0.32
Average sound level (dBL)	73.1	70.5	67.2	63.8	61.1	57.9	54.1	51.9	48.1	Average sound level (dBA)	83.5
Std. dev. of sound level (dBL)	2.8	2.5	2.0	1.7	1.6	2.1	2.1	2.4	2.7	Std. dev. of sound level (dBA)	1.8
Std. dev. of sound level residuals (dBL)	2.8	2.5	2.0	1.7	1.6	2.1	2.1	2.4	2.7	Std. dev. of sound level residuals (dBA)	1.7
L_{veh} at ref. speed (dBL)	72.9	70.4	67.0	63.7	61.0	57.7	54.0	51.9	48.0	L_{veh} at ref. speed (dBA)	83.3

Table C.6. Sound Level and Speed Regression Data Pavement Cell 8 (conventional grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	2	
Average speed* (km/h [mph])	114.6	[71.2]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	71.1	76.6	74.6	74.9	76.1	77.2	73.5	76.4	74.3	74.1	81.1	75.5	77.3	84.7	75.5
Std. dev. of sound level (dBL)	10.7	3.4	6.6	7.6	7.7	0.3	5.7	1.5	0.9	2.0	7.6	2.8	3.3	4.0	4.1
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	72.5	70.1	68.3	65.6	61.7	59.9	56.3	54.0	51.3	Average sound level (dBA)	88.2
Std. dev. of sound level (dBL)	3.1	2.7	3.7	4.1	3.7	4.2	4.7	5.4	4.5	Std. dev. of sound level (dBA)	2.0
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table C.7. Sound Level and Speed Regression Data Pavement Cell 8 (conventional grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	7	
Average speed* (km/h [mph])	107.5	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	281.48	201.48	-255.36	38.17	-36.91	1.55	65.86	37.31	265.36	75.33	-505.55	-351.87	16.76	-139.20	-309.40
Regr. line slope	-102.57	-60.68	167.19	19.62	56.32	37.77	6.49	19.07	-92.48	1.42	290.51	215.61	31.09	108.28	190.74
Correlation coefficient	-0.54	-0.17	0.60	0.21	0.65	0.51	0.15	0.17	-0.50	0.01	0.73	0.65	0.17	0.45	0.58
Average sound level (dBL)	73.1	78.2	84.3	78.0	77.5	78.3	79.0	76.1	77.5	78.2	84.6	86.2	79.9	80.8	78.1
Std. dev. of sound level (dBL)	3.8	7.4	5.6	1.9	1.7	1.5	0.9	2.3	3.7	1.9	8.0	6.7	3.6	4.8	6.6
Std. dev. of sound level residuals (dBL)	3.2	7.3	4.5	1.8	1.3	1.3	0.9	2.3	3.2	1.9	5.4	5.1	3.5	4.3	5.4
L_{veh} at ref. speed (dBL)	73.3	78.3	83.9	78.0	77.4	78.2	79.0	76.0	77.7	78.2	84.0	85.7	79.9	80.6	77.7

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-218.84	-271.97	-281.93	-324.53	-415.07	-504.07	-555.20	-593.64	-493.74	Regr. line intercept	-211.48
Regr. line slope	144.27	168.85	172.51	191.98	235.22	277.21	300.36	317.94	266.88	Regr. line slope	148.66
Correlation coefficient	0.55	0.49	0.49	0.47	0.50	0.55	0.55	0.56	0.54	Correlation coefficient	0.69
Average sound level (dBL)	74.3	71.1	68.5	65.5	62.8	59.1	55.0	52.3	48.4	Average sound level (dBA)	90.5
Std. dev. of sound level (dBL)	5.3	6.9	7.0	8.2	9.5	10.1	11.0	11.4	9.9	Std. dev. of sound level (dBA)	4.3
Std. dev. of sound level residuals (dBL)	4.4	6.1	6.1	7.2	8.2	8.5	9.1	9.5	8.3	Std. dev. of sound level residuals (dBA)	3.1
L_{veh} at ref. speed (dBL)	73.9	70.7	68.2	65.1	62.3	58.5	54.3	51.6	47.9	L_{veh} at ref. speed (dBA)	90.2

Table C.8. Sound Level and Speed Regression Data Pavement Cell 8 (conventional grind) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	9	
Average speed* (km/h [mph])	109.1	[67.8]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	402.82	232.66	-123.62	148.36	84.01	14.89	145.68	21.67	253.74	102.22	-326.19	-338.33	-20.96	-54.78	-318.07
Regr. line slope	-162.04	-75.98	100.97	-34.85	-3.35	30.99	-33.31	26.72	-86.85	-12.23	201.24	207.16	49.23	66.95	194.14
Correlation coefficient	-0.60	-0.22	0.35	-0.21	-0.02	0.45	-0.29	0.24	-0.50	-0.12	0.51	0.66	0.28	0.28	0.61
Average sound level (dBL)	72.6	77.8	82.1	77.3	77.2	78.0	77.8	76.1	76.8	77.3	83.9	83.8	79.3	81.6	77.5
Std. dev. of sound level (dBL)	5.0	6.5	5.4	3.1	3.1	1.3	2.2	2.1	3.2	1.8	7.4	5.9	3.3	4.4	5.9
Std. dev. of sound level residuals (dBL)	2.8	6.3	3.9	1.6	1.1	1.1	0.7	2.0	2.8	1.7	4.7	4.4	3.1	3.7	4.7
L_{veh} at ref. speed (dBL)	74.0	78.5	81.3	77.6	77.2	77.8	78.1	75.9	77.5	77.4	82.2	82.1	78.9	81.1	75.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-225.47	-266.26	-288.85	-332.27	-406.14	-491.83	-542.82	-587.45	-487.60	Regr. line intercept	-146.47
Regr. line slope	146.90	165.44	175.36	195.22	230.02	270.46	293.53	314.13	263.38	Regr. line slope	116.05
Correlation coefficient	0.58	0.51	0.53	0.50	0.52	0.57	0.57	0.58	0.56	Correlation coefficient	0.57
Average sound level (dBL)	73.9	70.9	68.5	65.5	62.6	59.3	55.3	52.6	49.1	Average sound level (dBA)	90.0
Std. dev. of sound level (dBL)	4.7	6.1	6.2	7.2	8.3	8.9	9.6	10.1	8.7	Std. dev. of sound level (dBA)	3.8
Std. dev. of sound level residuals (dBL)	3.8	5.2	5.3	6.2	7.1	7.3	7.9	8.2	7.2	Std. dev. of sound level residuals (dBA)	2.7
L_{veh} at ref. speed (dBL)	72.7	69.5	67.0	63.9	60.7	57.0	52.9	50.0	46.9	L_{veh} at ref. speed (dBA)	89.0

Table C.9. Sound Level and Speed Regression Data Pavement Cell 97 (transverse tine) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	49	
Average speed* (km/h [mph])	118.3	[73.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	43.85	72.52	54.01	68.71	58.78	47.76	15.43	91.02	78.49	66.67	61.13	59.82	128.01	51.00	30.73
Regr. line slope	9.51	-3.11	7.45	1.66	6.23	11.72	28.30	-7.66	-1.36	3.64	6.96	8.62	-23.04	14.87	24.10
Correlation coefficient	0.10	-0.03	0.06	0.01	0.06	0.13	0.29	-0.09	-0.02	0.04	0.06	0.07	-0.20	0.17	0.34
Average sound level (dBL)	63.6	66.1	69.5	72.2	71.7	72.1	74.1	75.1	75.7	74.2	75.5	77.7	80.3	81.8	80.7
Std. dev. of sound level (dBL)	2.9	3.5	3.9	4.0	3.1	2.5	2.8	2.6	2.2	2.6	3.4	3.3	3.3	2.5	2.1
Std. dev. of sound level residuals (dBL)	2.9	3.5	3.9	4.0	3.0	2.5	2.7	2.5	2.2	2.6	3.4	3.3	3.2	2.5	2.0
L_{veh} at ref. speed (dBL)	63.4	66.1	69.4	72.1	71.6	71.9	73.7	75.2	75.7	74.2	75.5	77.6	80.5	81.6	80.4

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	18.59	32.57	35.03	26.62	14.04	6.33	8.29	25.32	-1.95	Regr. line intercept	57.31
Regr. line slope	30.25	22.03	19.25	21.09	25.23	28.06	25.55	16.02	27.74	Regr. line slope	15.47
Correlation coefficient	0.34	0.20	0.17	0.26	0.38	0.40	0.41	0.23	0.41	Correlation coefficient	0.25
Average sound level (dBL)	81.3	78.2	74.9	70.3	66.3	64.5	61.3	58.5	55.6	Average sound level (dBA)	89.4
Std. dev. of sound level (dBL)	2.6	3.1	3.2	2.4	1.9	2.0	1.8	2.0	1.9	Std. dev. of sound level (dBA)	1.8
Std. dev. of sound level residuals (dBL)	2.4	3.1	3.1	2.3	1.8	1.8	1.6	2.0	1.8	Std. dev. of sound level residuals (dBA)	1.8
L_{veh} at ref. speed (dBL)	80.9	78.0	74.7	70.1	66.0	64.2	60.9	58.3	55.2	L_{veh} at ref. speed (dBA)	89.2

Table C.10. Sound Level and Speed Regression Data Pavement Cell 97 (transverse tine) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	2	
Average speed* (km/h [mph])	114.6	[71.2]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	71.3	73.9	77.2	77.5	80.8	78.3	80.4	84.5	78.7	80.7	83.8	84.5	82.5	86.9	80.9
Std. dev. of sound level (dBL)	5.6	7.8	6.4	5.1	5.7	0.7	3.1	4.0	1.1	5.4	6.2	0.4	0.4	0.2	4.0
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	79.3	75.1	73.2	71.2	67.6	66.1	64.8	62.2	59.8	Average sound level (dBA)	91.8
Std. dev. of sound level (dBL)	1.3	1.4	0.6	0.4	0.4	0.4	1.2	0.1	0.1	Std. dev. of sound level (dBA)	0.2
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table C.11. Sound Level and Speed Regression Data Pavement Cell 97 (transverse tine) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	7	
Average speed* (km/h [mph])	107.5	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-151.11	-328.65	-251.58	187.01	-60.05	94.90	144.84	169.93	232.33	194.11	-7.16	261.57	245.08	138.91	76.03
Regr. line slope	111.71	201.13	164.08	-50.67	70.49	-6.01	-28.88	-42.98	-73.27	-54.30	47.02	-85.13	-77.04	-25.12	5.19
Correlation coefficient	0.60	0.42	0.78	-0.44	0.36	-0.04	-0.31	-0.28	-0.68	-0.40	0.20	-0.55	-0.52	-0.44	0.06
Average sound level (dBL)	75.8	80.0	81.8	84.1	83.2	82.7	86.2	82.6	83.5	83.8	88.4	88.6	88.6	87.9	86.6
Std. dev. of sound level (dBL)	3.7	9.7	4.2	2.3	3.9	2.7	1.9	3.1	2.2	2.7	4.6	3.1	3.0	1.1	1.6
Std. dev. of sound level residuals (dBL)	3.0	8.8	2.7	2.1	3.7	2.7	1.8	2.9	1.6	2.5	4.5	2.6	2.6	1.0	1.6
L_{veh} at ref. speed (dBL)	75.6	79.5	81.4	84.2	83.0	82.7	86.2	82.7	83.6	83.9	88.3	88.8	88.7	87.9	86.6

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-7.57	84.05	91.37	69.53	51.79	6.19	44.07	33.78	31.31	Regr. line intercept	134.25
Regr. line slope	45.06	-2.36	-6.98	1.90	9.15	31.02	10.84	14.57	14.26	Regr. line slope	-18.97
Correlation coefficient	0.51	-0.05	-0.13	0.03	0.15	0.39	0.21	0.22	0.22	Correlation coefficient	-0.30
Average sound level (dBL)	84.0	79.2	77.2	73.4	70.4	69.2	66.1	63.4	60.3	Average sound level (dBA)	95.7
Std. dev. of sound level (dBL)	1.8	1.0	1.1	1.2	1.2	1.6	1.0	1.3	1.3	Std. dev. of sound level (dBA)	1.3
Std. dev. of sound level residuals (dBL)	1.5	1.0	1.1	1.2	1.2	1.5	1.0	1.3	1.2	Std. dev. of sound level residuals (dBA)	1.2
L_{veh} at ref. speed (dBL)	83.9	79.2	77.2	73.4	70.4	69.1	66.1	63.3	60.3	L_{veh} at ref. speed (dBA)	95.8

Table C.12. Sound Level and Speed Regression Data Pavement Cell 97 (transverse tine) at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	9	
Average speed* (km/h [mph])	109.1	[67.8]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-46.13	-170.74	-121.45	243.18	35.87	82.59	179.30	104.46	228.22	255.00	90.11	233.00	228.92	135.20	20.21
Regr. line slope	59.35	122.37	99.22	-78.80	22.95	-0.42	-46.34	-10.52	-71.56	-84.36	-1.35	-71.30	-69.55	-23.33	31.95
Correlation coefficient	0.29	0.26	0.43	-0.55	0.11	0.00	-0.44	-0.07	-0.70	-0.52	-0.01	-0.49	-0.50	-0.44	0.30
Average sound level (dBL)	74.8	78.6	80.7	82.6	82.6	81.7	84.9	83.0	82.4	83.1	87.4	87.7	87.2	87.7	85.3
Std. dev. of sound level (dBL)	3.8	8.8	4.3	2.7	4.0	2.4	2.0	3.0	1.9	3.0	4.6	2.7	2.6	1.0	2.0
Std. dev. of sound level residuals (dBL)	2.6	7.6	2.3	1.8	3.2	2.4	1.6	2.5	1.4	2.2	3.9	2.3	2.2	0.9	1.4
L_{veh} at ref. speed (dBL)	74.3	77.6	79.9	83.3	82.4	81.7	85.3	83.1	83.0	83.8	87.4	88.3	87.8	87.8	85.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-15.72	62.92	80.86	63.65	48.60	19.31	63.21	35.28	36.81	Regr. line intercept	130.69
Regr. line slope	48.41	7.56	-2.23	4.54	10.38	24.15	1.27	13.66	11.47	Regr. line slope	-17.59
Correlation coefficient	0.56	0.14	-0.04	0.08	0.18	0.32	0.02	0.22	0.19	Correlation coefficient	-0.30
Average sound level (dBL)	82.9	78.3	76.3	72.9	69.8	68.5	65.8	63.1	60.2	Average sound level (dBA)	94.8
Std. dev. of sound level (dBL)	1.6	1.0	0.9	1.1	1.1	1.4	1.0	1.1	1.1	Std. dev. of sound level (dBA)	1.1
Std. dev. of sound level residuals (dBL)	1.3	0.9	0.9	1.1	1.0	1.3	0.9	1.1	1.1	Std. dev. of sound level residuals (dBA)	1.0
L_{veh} at ref. speed (dBL)	82.5	78.3	76.3	72.9	69.7	68.3	65.8	63.0	60.1	L_{veh} at ref. speed (dBA)	95.0

Table C.13. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 25’ microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	104	
Average speed* (km/h [mph])	115.2	[71.6]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	36.00	79.18	39.36	70.05	62.89	-12.85	5.90	7.04	-7.82	47.68	41.34	54.26	64.86	24.91	31.55
Regr. line slope	13.34	-6.23	14.04	-0.24	3.42	39.87	30.81	30.87	38.07	11.03	14.59	9.44	5.72	25.73	22.00
Correlation coefficient	0.09	-0.04	0.08	0.00	0.02	0.23	0.20	0.25	0.31	0.08	0.11	0.06	0.04	0.27	0.29
Average sound level (dBL)	63.5	66.3	68.3	69.6	69.9	69.3	69.4	70.7	70.7	70.4	71.4	73.7	76.6	77.9	76.9
Std. dev. of sound level (dBL)	3.9	4.1	4.9	4.4	5.0	4.6	4.1	3.3	3.2	3.5	3.5	4.2	3.6	2.6	2.0
Std. dev. of sound level residuals (dBL)	3.9	4.1	4.9	4.4	5.0	4.5	4.0	3.2	3.1	3.5	3.5	4.1	3.6	2.5	2.0
L_{veh} at ref. speed (dBL)	63.5	66.3	68.3	69.6	69.9	69.3	69.4	70.6	70.6	70.4	71.4	73.7	76.6	77.9	76.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	52.55	36.27	37.19	30.11	25.85	23.49	35.86	23.37	2.85	Regr. line intercept	50.14
Regr. line slope	11.77	18.91	16.65	18.45	18.93	18.44	11.19	15.69	23.71	Regr. line slope	17.21
Correlation coefficient	0.15	0.20	0.18	0.22	0.23	0.20	0.11	0.16	0.29	Correlation coefficient	0.24
Average sound level (dBL)	76.8	75.2	71.5	68.2	64.9	61.5	58.9	55.7	51.7	Average sound level (dBA)	85.6
Std. dev. of sound level (dBL)	2.1	2.5	2.5	2.3	2.2	2.5	2.7	2.6	2.2	Std. dev. of sound level (dBA)	1.9
Std. dev. of sound level residuals (dBL)	2.1	2.5	2.5	2.2	2.2	2.5	2.7	2.5	2.1	Std. dev. of sound level residuals (dBA)	1.9
L_{veh} at ref. speed (dBL)	76.8	75.2	71.5	68.1	64.8	61.5	58.9	55.7	51.7	L_{veh} at ref. speed (dBA)	85.6

Table C.14. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	25
Average speed* (km/h [mph])	105.7 [65.7]
St. dev. of speed* (km/h [mph])	1.1 [0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	41.56	14.85	137.60	71.14	79.39	6.07	32.12	73.04	-4.71	39.25	55.14	-12.96	43.60	-4.27	-13.31
Regr. line slope	14.83	28.71	-30.23	3.82	0.06	35.32	22.32	1.59	40.91	19.33	13.08	47.49	18.38	41.87	45.90
Correlation coefficient	0.14	0.29	-0.19	0.03	0.00	0.32	0.27	0.03	0.39	0.19	0.09	0.32	0.26	0.53	0.56
Average sound level (dBL)	71.6	73.0	76.4	78.9	79.5	77.6	77.3	76.3	78.1	78.4	81.6	83.2	80.8	80.5	79.6
Std. dev. of sound level (dBL)	4.2	3.9	6.1	4.4	4.3	4.3	3.2	2.2	4.2	4.1	5.5	5.8	2.8	3.1	3.2
Std. dev. of sound level residuals (dBL)	4.1	3.7	6.0	4.4	4.3	4.1	3.1	2.2	3.8	4.0	5.5	5.5	2.7	2.6	2.6
L_{veh} at ref. speed (dBL)	71.7	73.1	76.3	78.9	79.5	77.8	77.4	76.3	78.3	78.5	81.7	83.4	80.9	80.7	79.8

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	24.56	8.58	25.34	19.20	-12.27	-18.74	-19.18	-2.73	-6.99	Regr. line intercept	-1.02
Regr. line slope	26.16	33.02	23.56	25.51	39.88	41.89	41.05	31.51	32.11	Regr. line slope	44.91
Correlation coefficient	0.48	0.52	0.47	0.43	0.60	0.62	0.66	0.52	0.44	Correlation coefficient	0.58
Average sound level (dBL)	77.5	75.4	73.0	70.8	68.5	66.1	63.9	61.0	58.0	Average sound level (dBA)	89.9
Std. dev. of sound level (dBL)	2.1	2.5	2.0	2.3	2.6	2.6	2.4	2.4	2.8	Std. dev. of sound level (dBA)	3.0
Std. dev. of sound level residuals (dBL)	1.9	2.1	1.7	2.1	2.1	2.1	1.8	2.0	2.5	Std. dev. of sound level residuals (dBA)	2.5
L_{veh} at ref. speed (dBL)	77.7	75.6	73.2	71.0	68.7	66.3	64.1	61.2	58.2	L_{veh} at ref. speed (dBA)	90.1

Table C.15. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 25’ microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	52	
Average speed* (km/h [mph])	107.6	[66.9]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	52.48	128.75	75.07	48.39	49.27	69.36	80.35	19.69	44.71	79.70	-0.61	-59.98	69.16	9.32	26.45
Regr. line slope	10.47	-25.70	4.32	15.83	15.28	5.94	0.54	29.67	18.21	1.12	43.61	72.66	7.74	37.75	27.88
Correlation coefficient	0.06	-0.13	0.02	0.09	0.15	0.05	0.00	0.21	0.11	0.01	0.20	0.39	0.07	0.27	0.29
Average sound level (dBL)	73.8	76.5	83.9	80.6	80.3	81.4	81.5	80.0	81.7	82.0	88.0	87.6	84.9	86.0	83.1
Std. dev. of sound level (dBL)	3.7	4.4	6.0	3.9	2.3	2.4	2.7	3.1	3.7	2.6	4.9	4.2	2.4	3.1	2.1
Std. dev. of sound level residuals (dBL)	3.7	4.4	6.0	3.8	2.3	2.4	2.7	3.1	3.7	2.6	4.8	3.8	2.4	3.0	2.0
L_{veh} at ref. speed (dBL)	73.7	76.6	83.8	80.5	80.3	81.4	81.5	79.9	81.7	82.0	87.9	87.5	84.9	85.9	83.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	28.42	53.52	32.19	20.88	3.58	-2.72	-20.37	-10.39	-1.09	Regr. line intercept	10.59
Regr. line slope	25.84	12.37	21.54	26.05	33.61	35.61	43.36	36.87	30.05	Regr. line slope	41.13
Correlation coefficient	0.26	0.13	0.23	0.31	0.36	0.33	0.48	0.41	0.34	Correlation coefficient	0.44
Average sound level (dBL)	80.9	78.7	76.0	73.8	71.9	69.6	67.7	64.5	60.0	Average sound level (dBA)	94.2
Std. dev. of sound level (dBL)	2.2	2.1	2.1	1.9	2.1	2.4	2.0	2.0	2.0	Std. dev. of sound level (dBA)	2.1
Std. dev. of sound level residuals (dBL)	2.2	2.1	2.0	1.8	1.9	2.2	1.7	1.8	1.8	Std. dev. of sound level residuals (dBA)	1.9
L_{veh} at ref. speed (dBL)	80.9	78.6	75.9	73.7	71.8	69.5	67.6	64.4	59.9	L_{veh} at ref. speed (dBA)	94.1

Table C.16. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	77	
Average speed* (km/h [mph])	107.0	[66.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	46.55	61.99	114.28	62.35	67.38	32.73	52.77	52.38	16.24	56.60	34.20	-30.94	55.04	2.66	3.68
Regr. line slope	13.06	6.59	-16.18	8.70	6.25	23.38	13.47	13.01	31.69	11.93	25.49	57.72	14.06	40.20	38.58
Correlation coefficient	0.10	0.04	-0.08	0.06	0.06	0.21	0.13	0.13	0.24	0.11	0.14	0.35	0.16	0.37	0.44
Average sound level (dBL)	73.0	75.4	81.4	80.0	80.1	80.2	80.1	78.8	80.5	80.8	85.9	86.2	83.6	84.2	82.0
Std. dev. of sound level (dBL)	3.8	4.2	6.0	4.0	3.1	3.1	2.9	2.9	3.8	3.1	5.1	4.7	2.5	3.1	2.5
Std. dev. of sound level residuals (dBL)	3.8	4.1	5.9	4.0	3.1	3.0	2.8	2.8	3.7	3.1	5.0	4.4	2.5	2.8	2.2
L_{veh} at ref. speed (dBL)	73.0	75.4	81.4	80.0	80.1	80.2	80.1	78.8	80.5	80.8	85.9	86.2	83.6	84.2	82.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	26.99	27.63	28.86	20.63	-5.00	-11.36	-18.72	-4.97	-4.13	Regr. line intercept	4.75
Regr. line slope	26.03	24.63	22.74	25.73	37.33	39.34	41.99	33.69	31.28	Regr. line slope	43.37
Correlation coefficient	0.34	0.31	0.32	0.36	0.48	0.46	0.56	0.46	0.40	Correlation coefficient	0.51
Average sound level (dBL)	79.8	77.6	75.0	72.8	70.8	68.5	66.5	63.4	59.3	Average sound level (dBA)	92.8
Std. dev. of sound level (dBL)	2.2	2.2	2.0	2.0	2.2	2.4	2.1	2.1	2.3	Std. dev. of sound level (dBA)	2.4
Std. dev. of sound level residuals (dBL)	2.1	2.1	1.9	1.9	2.0	2.2	1.8	1.9	2.1	Std. dev. of sound level residuals (dBA)	2.1
L_{veh} at ref. speed (dBL)	79.8	77.6	75.0	72.8	70.8	68.5	66.5	63.4	59.3	L_{veh} at ref. speed (dBA)	92.8

Table C.17. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 50' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	59	
Average speed* (km/h [mph])	115.2	[71.6]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	26.65	30.89	35.75	38.76	71.80	-4.73	5.82	-41.99	-35.28	19.24	12.74	33.56	67.61	13.16	23.57
Regr. line slope	17.50	16.46	14.95	13.10	-3.64	33.20	27.42	51.30	47.91	21.41	25.16	16.77	2.06	28.53	22.77
Correlation coefficient	0.14	0.12	0.14	0.09	-0.02	0.23	0.21	0.43	0.43	0.17	0.21	0.12	0.02	0.34	0.33
Average sound level (dBL)	62.7	64.8	66.6	65.8	64.3	63.7	62.4	63.8	63.5	63.4	64.6	68.1	71.9	72.0	70.5
Std. dev. of sound level (dBL)	3.6	4.1	3.3	4.3	4.5	4.2	3.9	3.6	3.3	3.8	3.6	4.2	3.8	2.5	2.0
Std. dev. of sound level residuals (dBL)	3.6	4.0	3.2	4.3	4.5	4.1	3.8	3.2	3.0	3.7	3.5	4.2	3.8	2.4	1.9
L_{veh} at ref. speed (dBL)	62.7	64.8	66.6	65.7	64.3	63.7	62.3	63.7	63.4	63.4	64.6	68.1	71.9	72.0	70.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	42.52	19.60	13.59	6.01	6.23	18.51	13.17	0.96	-22.26	Regr. line intercept	35.53
Regr. line slope	13.21	23.58	25.10	27.27	25.86	18.51	19.81	24.11	33.22	Regr. line slope	21.29
Correlation coefficient	0.20	0.33	0.36	0.37	0.34	0.23	0.22	0.30	0.43	Correlation coefficient	0.32
Average sound level (dBL)	69.8	68.2	65.3	62.2	59.5	56.7	54.0	50.7	46.2	Average sound level (dBA)	79.4
Std. dev. of sound level (dBL)	1.9	2.2	2.1	2.2	2.3	2.4	2.7	2.4	2.3	Std. dev. of sound level (dBA)	2.0
Std. dev. of sound level residuals (dBL)	1.9	2.0	1.9	2.1	2.1	2.3	2.6	2.3	2.1	Std. dev. of sound level residuals (dBA)	1.9
L_{veh} at ref. speed (dBL)	69.7	68.2	65.3	62.2	59.5	56.7	54.0	50.6	46.2	L_{veh} at ref. speed (dBA)	79.4

Table C.18. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 50’ microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	14
Average speed* (km/h [mph])	108.3 [67.3]
St. dev. of speed* (km/h [mph])	1.1 [0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-17.75	74.23	162.95	-57.10	92.62	102.87	-3.55	-51.47	-25.57	104.76	119.50	-32.93	77.23	53.08	39.30
Regr. line slope	42.45	-1.30	-44.78	63.67	-10.66	-16.12	35.69	59.30	47.03	-16.68	-22.52	53.94	-0.98	9.83	16.46
Correlation coefficient	0.36	-0.01	-0.29	0.35	-0.08	-0.13	0.31	0.59	0.38	-0.11	-0.14	0.24	-0.01	0.18	0.24
Average sound level (dBL)	68.6	71.6	71.8	72.4	70.9	70.1	69.1	69.2	70.1	70.8	73.7	76.8	75.2	73.1	72.8
Std. dev. of sound level (dBL)	3.7	4.1	4.8	5.8	4.4	3.9	3.7	3.2	3.9	4.9	5.1	7.1	2.3	1.7	2.2
Std. dev. of sound level residuals (dBL)	3.5	4.1	4.6	5.4	4.4	3.9	3.5	2.6	3.6	4.9	5.1	6.9	2.3	1.7	2.2
L_{veh} at ref. speed (dBL)	68.4	71.6	72.1	72.1	71.0	70.2	68.9	68.9	69.9	70.9	73.8	76.5	75.2	73.0	72.7

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	35.55	29.45	46.57	24.90	6.97	3.58	17.61	42.79	52.83	Regr. line intercept	5.05
Regr. line slope	17.46	19.65	10.09	19.46	27.20	27.67	19.59	5.86	-0.52	Regr. line slope	38.50
Correlation coefficient	0.45	0.48	0.24	0.37	0.49	0.39	0.40	0.11	-0.01	Correlation coefficient	0.38
Average sound level (dBL)	71.1	69.4	67.1	64.5	62.3	59.9	57.5	54.7	51.8	Average sound level (dBA)	83.4
Std. dev. of sound level (dBL)	1.2	1.3	1.3	1.7	1.7	2.3	1.6	1.6	2.6	Std. dev. of sound level (dBA)	3.2
Std. dev. of sound level residuals (dBL)	1.1	1.2	1.3	1.5	1.5	2.1	1.4	1.6	2.6	Std. dev. of sound level residuals (dBA)	3.0
L_{veh} at ref. speed (dBL)	71.0	69.3	67.0	64.4	62.2	59.7	57.4	54.7	51.8	L_{veh} at ref. speed (dBA)	83.2

Table C.19. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 50' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	45	
Average speed* (km/h [mph])	107.6	[66.9]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	54.68	50.67	78.56	-23.93	7.22	3.86	7.23	8.40	74.13	118.85	-17.96	-59.46	75.12	10.53	16.87
Regr. line slope	8.51	10.89	0.27	47.85	31.92	34.14	32.62	31.55	0.13	-21.18	49.06	69.12	1.36	33.66	29.15
Correlation coefficient	0.06	0.07	0.00	0.32	0.29	0.27	0.26	0.25	0.00	-0.14	0.22	0.35	0.01	0.31	0.30
Average sound level (dBL)	72.0	72.8	79.1	73.3	72.1	73.2	73.5	72.5	74.4	75.8	81.7	81.0	77.9	78.9	76.1
Std. dev. of sound level (dBL)	3.1	3.4	5.9	3.4	2.5	2.9	2.9	2.9	3.6	3.4	5.0	4.6	2.3	2.5	2.2
Std. dev. of sound level residuals (dBL)	3.1	3.4	5.9	3.2	2.4	2.8	2.8	2.8	3.6	3.3	4.9	4.3	2.3	2.4	2.1
L_{veh} at ref. speed (dBL)	71.9	72.8	79.1	73.2	72.0	73.1	73.4	72.4	74.4	75.9	81.6	80.8	77.9	78.8	76.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	10.79	35.10	35.06	22.82	-0.44	-11.18	-11.36	-7.44	-7.90	Regr. line intercept	10.72
Regr. line slope	31.02	18.00	16.92	21.88	32.32	36.69	35.80	32.15	30.18	Regr. line slope	37.77
Correlation coefficient	0.34	0.25	0.23	0.30	0.33	0.35	0.41	0.36	0.38	Correlation coefficient	0.43
Average sound level (dBL)	73.8	71.7	69.4	67.3	65.2	63.4	61.4	57.9	53.4	Average sound level (dBA)	87.5
Std. dev. of sound level (dBL)	2.1	1.6	1.7	1.7	2.2	2.4	2.0	2.0	1.8	Std. dev. of sound level (dBA)	2.0
Std. dev. of sound level residuals (dBL)	1.9	1.6	1.6	1.6	2.1	2.3	1.8	1.9	1.7	Std. dev. of sound level residuals (dBA)	1.8
L_{veh} at ref. speed (dBL)	73.7	71.6	69.4	67.2	65.1	63.3	61.3	57.8	53.4	L_{veh} at ref. speed (dBA)	87.4

Table C.20. Sound Level and Speed Regression Data Control Pavement (burlap drag) on I-94, measured Wednesday, September 02, 2009 50' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	59	
Average speed* (km/h [mph])	107.8	[67.0]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	28.92	59.34	109.96	-35.80	38.24	40.05	3.90	-12.81	38.63	114.37	32.73	-49.33	76.21	26.64	25.40
Regr. line slope	20.79	6.48	-16.03	53.57	16.51	15.96	33.73	41.59	17.10	-19.55	23.17	63.63	0.51	25.04	24.56
Correlation coefficient	0.16	0.05	-0.07	0.33	0.14	0.13	0.28	0.36	0.12	-0.13	0.12	0.31	0.01	0.27	0.28
Average sound level (dBL)	71.2	72.5	77.4	73.1	71.8	72.5	72.5	71.7	73.4	74.6	79.8	80.0	77.3	77.5	75.3
Std. dev. of sound level (dBL)	3.2	3.5	5.7	4.1	3.0	3.1	3.1	2.9	3.7	3.7	5.0	5.2	2.3	2.3	2.2
Std. dev. of sound level residuals (dBL)	3.2	3.5	5.6	3.8	2.9	3.1	2.9	2.7	3.6	3.7	4.9	4.9	2.3	2.2	2.1
L_{veh} at ref. speed (dBL)	71.1	72.5	77.4	72.9	71.7	72.4	72.3	71.6	73.3	74.7	79.7	79.8	77.2	77.4	75.2

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	20.09	33.34	39.52	23.92	2.61	-5.40	-0.39	11.12	14.27	Regr. line intercept	9.19
Regr. line slope	26.11	18.60	14.45	21.00	30.47	33.43	29.93	22.64	19.08	Regr. line slope	38.03
Correlation coefficient	0.34	0.30	0.22	0.32	0.36	0.35	0.40	0.29	0.23	Correlation coefficient	0.41
Average sound level (dBL)	73.2	71.1	68.9	66.6	64.5	62.5	60.4	57.1	53.0	Average sound level (dBA)	86.5
Std. dev. of sound level (dBL)	1.9	1.6	1.6	1.7	2.1	2.4	1.9	1.9	2.0	Std. dev. of sound level (dBA)	2.3
Std. dev. of sound level residuals (dBL)	1.8	1.5	1.6	1.6	2.0	2.2	1.7	1.8	1.9	Std. dev. of sound level residuals (dBA)	2.1
L_{veh} at ref. speed (dBL)	73.1	71.1	68.8	66.5	64.4	62.4	60.4	57.1	53.0	L_{veh} at ref. speed (dBA)	86.4

Table C.21. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	101	
Average speed* (km/h [mph])	115.1	[71.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	66.03	31.68	103.48	54.60	36.71	37.90	12.51	38.83	49.71	61.84	33.01	102.13	101.83	31.62	8.64
Regr. line slope	-1.12	16.84	-16.67	7.58	15.90	15.75	27.71	14.87	9.48	3.45	18.14	-14.40	-12.17	22.01	31.26
Correlation coefficient	-0.01	0.12	-0.14	0.06	0.12	0.12	0.23	0.11	0.07	0.03	0.14	-0.09	-0.09	0.21	0.28
Average sound level (dBL)	63.7	66.4	69.1	70.2	69.5	70.4	69.6	69.5	69.2	68.9	70.4	72.5	76.7	77.0	73.1
Std. dev. of sound level (dBL)	3.7	4.0	3.5	3.9	3.8	4.0	3.4	3.8	3.8	3.1	3.8	4.7	4.0	3.1	3.2
Std. dev. of sound level residuals (dBL)	3.7	3.9	3.4	3.9	3.8	3.9	3.3	3.8	3.8	3.1	3.8	4.6	4.0	3.0	3.1
L_{veh} at ref. speed (dBL)	63.7	66.4	69.1	70.2	69.5	70.3	69.6	69.5	69.2	68.9	70.4	72.5	76.7	77.0	73.1

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	69.48	48.18	42.28	24.27	9.09	7.54	-4.97	-16.41	-24.44	Regr. line intercept	74.65
Regr. line slope	0.77	10.19	11.84	19.16	25.05	24.23	28.83	33.04	35.43	Regr. line slope	4.10
Correlation coefficient	0.01	0.11	0.13	0.22	0.28	0.25	0.27	0.29	0.32	Correlation coefficient	0.05
Average sound level (dBL)	71.1	69.2	66.7	63.8	60.7	57.5	54.5	51.7	48.6	Average sound level (dBA)	83.1
Std. dev. of sound level (dBL)	3.3	2.7	2.6	2.5	2.6	2.8	3.1	3.3	3.2	Std. dev. of sound level (dBA)	2.6
Std. dev. of sound level residuals (dBL)	3.3	2.7	2.6	2.4	2.5	2.7	3.0	3.2	3.1	Std. dev. of sound level residuals (dBA)	2.6
L_{veh} at ref. speed (dBL)	71.1	69.2	66.7	63.8	60.7	57.5	54.4	51.7	48.6	L_{veh} at ref. speed (dBA)	83.1

Table C.22. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	27	
Average speed* (km/h [mph])	107.7	[66.9]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-22.14	-21.44	107.90	2.50	-25.36	73.21	-127.36	81.52	32.06	-20.30	121.91	71.43	-33.97	71.34	62.80
Regr. line slope	44.73	46.22	-16.80	36.72	50.32	1.01	100.49	-2.80	22.10	47.84	-21.41	4.66	57.07	3.72	6.48
Correlation coefficient	0.26	0.27	-0.11	0.17	0.22	0.01	0.51	-0.02	0.10	0.22	-0.10	0.02	0.36	0.03	0.05
Average sound level (dBL)	68.8	72.5	73.8	77.1	76.9	75.3	76.8	75.8	77.0	76.9	78.4	80.9	82.0	78.9	76.0
Std. dev. of sound level (dBL)	4.2	4.2	3.7	5.4	5.7	3.3	4.8	3.6	5.1	5.3	5.4	5.8	3.8	3.4	3.2
Std. dev. of sound level residuals (dBL)	4.1	4.1	3.7	5.3	5.6	3.3	4.1	3.6	5.1	5.2	5.3	5.8	3.6	3.4	3.2
L_{veh} at ref. speed (dBL)	68.6	72.4	73.8	77.0	76.8	75.3	76.6	75.8	76.9	76.8	78.5	80.9	81.9	78.9	76.0

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	64.77	56.30	45.03	28.62	29.40	15.65	-26.26	-3.54	46.78	Regr. line intercept	45.68
Regr. line slope	5.27	8.27	12.75	19.80	18.38	23.78	43.23	30.54	4.76	Regr. line slope	21.15
Correlation coefficient	0.05	0.07	0.11	0.17	0.13	0.15	0.28	0.20	0.02	Correlation coefficient	0.17
Average sound level (dBL)	75.5	73.1	70.9	68.9	66.8	64.0	61.6	58.5	56.4	Average sound level (dBA)	88.7
Std. dev. of sound level (dBL)	2.6	3.0	2.9	2.8	3.3	3.8	3.8	3.7	4.8	Std. dev. of sound level (dBA)	3.1
Std. dev. of sound level residuals (dBL)	2.6	3.0	2.9	2.7	3.3	3.7	3.6	3.7	4.8	Std. dev. of sound level residuals (dBA)	3.1
L_{veh} at ref. speed (dBL)	75.5	73.1	70.9	68.8	66.7	63.9	61.5	58.4	56.4	L_{veh} at ref. speed (dBA)	88.6

Table C.23. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	52	
Average speed* (km/h [mph])	106.3	[66.1]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-32.11	72.17	7.55	11.19	22.21	-13.39	18.24	-76.80	1.53	8.00	30.01	-41.55	-27.09	-30.72	-51.84
Regr. line slope	52.37	1.89	38.11	33.93	28.26	46.17	30.57	76.89	38.28	35.63	28.53	63.11	54.32	56.15	65.22
Correlation coefficient	0.36	0.01	0.17	0.23	0.25	0.25	0.23	0.46	0.21	0.30	0.12	0.34	0.37	0.44	0.53
Average sound level (dBL)	74.0	76.0	84.8	80.0	79.5	80.2	80.2	79.0	79.1	80.2	87.8	86.4	83.0	83.1	80.3
Std. dev. of sound level (dBL)	3.9	3.8	5.8	3.9	2.9	4.9	3.5	4.4	4.9	3.1	6.1	4.9	3.9	3.3	3.2
Std. dev. of sound level residuals (dBL)	3.6	3.8	5.7	3.8	2.8	4.7	3.4	3.9	4.8	3.0	6.0	4.6	3.6	3.0	2.7
L_{veh} at ref. speed (dBL)	74.2	76.0	84.9	80.1	79.6	80.3	80.3	79.2	79.2	80.3	87.9	86.5	83.2	83.2	80.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-32.90	3.27	3.38	-5.37	-14.03	-17.32	-27.09	-36.82	29.20	Regr. line intercept	-15.54
Regr. line slope	54.38	35.48	34.39	37.87	41.13	41.39	44.88	48.46	14.15	Regr. line slope	53.46
Correlation coefficient	0.51	0.36	0.35	0.38	0.37	0.40	0.38	0.33	0.11	Correlation coefficient	0.49
Average sound level (dBL)	77.3	75.2	73.1	71.4	69.3	66.6	63.9	61.4	57.9	Average sound level (dBA)	92.8
Std. dev. of sound level (dBL)	2.8	2.6	2.6	2.6	2.9	2.7	3.1	3.9	3.5	Std. dev. of sound level (dBA)	2.9
Std. dev. of sound level residuals (dBL)	2.4	2.4	2.4	2.4	2.7	2.5	2.9	3.7	3.5	Std. dev. of sound level residuals (dBA)	2.5
L_{veh} at ref. speed (dBL)	77.5	75.3	73.2	71.5	69.4	66.7	64.0	61.5	57.9	L_{veh} at ref. speed (dBA)	92.9

Table C.24. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 25’ microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	79	
Average speed* (km/h [mph])	106.8	[66.4]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-29.31	43.67	37.52	8.44	7.69	12.65	-26.01	-28.97	10.69	-0.71	57.49	-7.54	-29.22	0.03	-17.28
Regr. line slope	50.05	15.35	21.45	34.78	34.96	32.47	51.79	52.70	33.37	39.34	13.37	45.37	55.16	40.24	47.39
Correlation coefficient	0.32	0.10	0.11	0.20	0.22	0.19	0.33	0.33	0.17	0.25	0.06	0.22	0.37	0.31	0.38
Average sound level (dBL)	72.2	74.8	81.0	79.0	78.6	78.5	79.1	77.9	78.4	79.1	84.6	84.5	82.7	81.7	78.9
Std. dev. of sound level (dBL)	4.0	3.9	5.1	4.4	4.1	4.4	4.0	4.1	4.9	4.0	5.8	5.2	3.8	3.3	3.2
Std. dev. of sound level residuals (dBL)	3.8	3.9	5.1	4.3	3.9	4.3	3.7	3.8	4.9	3.8	5.8	5.0	3.6	3.1	2.9
L_{veh} at ref. speed (dBL)	72.3	74.8	81.0	79.0	78.6	78.5	79.1	78.0	78.4	79.1	84.6	84.5	82.7	81.7	78.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-3.39	19.25	15.91	4.82	-0.98	-7.44	-26.94	-26.86	34.46	Regr. line intercept	2.84
Regr. line slope	39.47	27.22	27.82	32.39	34.23	36.04	44.38	43.02	11.30	Regr. line slope	43.65
Correlation coefficient	0.37	0.25	0.26	0.31	0.29	0.30	0.34	0.29	0.07	Correlation coefficient	0.38
Average sound level (dBL)	76.7	74.5	72.3	70.5	68.5	65.7	63.1	60.4	57.4	Average sound level (dBA)	91.4
Std. dev. of sound level (dBL)	2.7	2.7	2.7	2.7	3.0	3.1	3.3	3.8	4.0	Std. dev. of sound level (dBA)	2.9
Std. dev. of sound level residuals (dBL)	2.5	2.6	2.6	2.5	2.9	3.0	3.1	3.7	4.0	Std. dev. of sound level residuals (dBA)	2.7
L_{veh} at ref. speed (dBL)	76.7	74.5	72.4	70.5	68.5	65.7	63.1	60.4	57.4	L_{veh} at ref. speed (dBA)	91.4

Table C.25. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 50' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	32	
Average speed* (km/h [mph])	115.8	[72.0]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	0.48	29.68	39.56	47.73	2.85	-17.73	-22.87	11.48	42.16	81.05	52.91	104.96	56.81	80.29	81.97
Regr. line slope	31.04	18.22	15.28	9.77	27.97	39.25	40.97	25.15	10.09	-8.79	5.65	-18.29	7.27	-4.20	-6.87
Correlation coefficient	0.22	0.13	0.10	0.08	0.23	0.33	0.26	0.15	0.07	-0.06	0.03	-0.09	0.04	-0.03	-0.06
Average sound level (dBL)	64.6	67.3	71.1	67.9	60.6	63.3	61.7	63.4	63.0	62.9	64.6	67.2	71.8	71.6	67.8
Std. dev. of sound level (dBL)	3.6	3.7	4.0	3.3	3.2	3.1	4.0	4.4	4.0	3.7	4.3	5.1	4.7	3.3	3.2
Std. dev. of sound level residuals (dBL)	3.5	3.7	4.0	3.3	3.1	2.9	3.9	4.3	3.9	3.7	4.3	5.1	4.7	3.3	3.2
L_{veh} at ref. speed (dBL)	64.5	67.2	71.1	67.9	60.5	63.2	61.5	63.3	63.0	62.9	64.5	67.3	71.8	71.6	67.8

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	53.92	45.40	65.96	14.11	-6.20	12.58	-15.47	-42.70	-52.01	Regr. line intercept	83.27
Regr. line slope	5.59	8.91	-2.15	21.68	30.08	19.47	31.69	43.26	45.84	Regr. line slope	-2.60
Correlation coefficient	0.05	0.09	-0.02	0.28	0.35	0.22	0.32	0.34	0.35	Correlation coefficient	-0.02
Average sound level (dBL)	65.5	63.8	61.5	58.9	55.9	52.8	49.9	46.6	42.6	Average sound level (dBA)	77.9
Std. dev. of sound level (dBL)	3.2	2.6	2.2	2.0	2.2	2.3	2.6	3.3	3.4	Std. dev. of sound level (dBA)	2.7
Std. dev. of sound level residuals (dBL)	3.2	2.6	2.2	1.9	2.1	2.2	2.5	3.1	3.2	Std. dev. of sound level residuals (dBA)	2.7
L_{veh} at ref. speed (dBL)	65.4	63.8	61.5	58.8	55.8	52.7	49.8	46.5	42.4	L_{veh} at ref. speed (dBA)	77.9

Table C.26. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 50' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	11	
Average speed* (km/h [mph])	107.6	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	307.47	-22.16	275.92	240.25	338.86	178.40	88.98	65.13	204.95	240.32	289.38	-11.25	-105.01	115.67	205.89
Regr. line slope	-117.13	46.07	-100.16	-83.14	-134.34	-54.72	-10.25	1.36	-65.71	-83.17	-106.31	43.65	89.36	-20.91	-65.95
Correlation coefficient	-0.54	0.23	-0.63	-0.28	-0.48	-0.35	-0.07	0.01	-0.20	-0.33	-0.32	0.13	0.39	-0.11	-0.33
Average sound level (dBL)	69.5	71.4	72.4	71.3	65.9	67.2	68.1	67.9	71.4	71.3	73.4	77.4	76.5	73.2	71.9
Std. dev. of sound level (dBL)	3.7	3.4	2.8	5.1	4.8	2.7	2.6	2.8	5.8	4.3	5.7	5.9	3.9	3.3	3.5
Std. dev. of sound level residuals (dBL)	3.1	3.3	2.1	4.9	4.2	2.5	2.6	2.8	5.7	4.1	5.4	5.9	3.6	3.3	3.3
L_{veh} at ref. speed (dBL)	69.8	71.3	72.7	71.5	66.2	67.4	68.2	67.9	71.6	71.5	73.6	77.3	76.3	73.2	72.1

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	78.03	92.84	76.63	16.07	-75.75	-78.36	-73.23	16.64	9.24	Regr. line intercept	101.32
Regr. line slope	-4.34	-12.76	-5.93	23.33	67.70	67.64	63.68	18.11	20.67	Regr. line slope	-8.65
Correlation coefficient	-0.03	-0.10	-0.03	0.10	0.26	0.31	0.29	0.08	0.08	Correlation coefficient	-0.05
Average sound level (dBL)	69.2	66.9	64.6	63.5	61.8	59.1	56.1	53.4	51.2	Average sound level (dBA)	83.7
Std. dev. of sound level (dBL)	2.4	2.2	3.2	4.2	4.6	3.7	3.8	4.1	4.6	Std. dev. of sound level (dBA)	2.9
Std. dev. of sound level residuals (dBL)	2.4	2.2	3.2	4.2	4.4	3.5	3.6	4.1	4.6	Std. dev. of sound level residuals (dBA)	2.9
L_{veh} at ref. speed (dBL)	69.2	66.9	64.6	63.4	61.6	58.9	56.0	53.4	51.2	L_{veh} at ref. speed (dBA)	83.8

Table C.27. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 50' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	35	
Average speed* (km/h [mph])	107.1	[66.6]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-6.54	104.93	0.78	-26.73	4.86	-7.01	45.91	-45.11	13.97	-5.31	-9.56	-37.12	-41.63	-59.94	-61.72
Regr. line slope	38.78	-15.48	41.41	50.36	31.43	40.07	12.94	57.80	29.04	39.21	44.79	56.94	57.96	67.27	66.82
Correlation coefficient	0.29	-0.08	0.19	0.35	0.21	0.20	0.09	0.36	0.15	0.25	0.19	0.30	0.38	0.49	0.49
Average sound level (dBL)	72.2	73.5	84.8	75.5	68.7	74.3	72.2	72.2	72.9	74.3	81.4	78.5	76.0	76.6	73.9
Std. dev. of sound level (dBL)	3.4	4.6	5.5	3.6	3.8	5.0	3.5	4.1	4.8	3.9	5.9	4.8	3.9	3.5	3.4
Std. dev. of sound level residuals (dBL)	3.2	4.6	5.4	3.4	3.7	4.9	3.4	3.8	4.8	3.8	5.8	4.6	3.6	3.0	3.0
L_{veh} at ref. speed (dBL)	72.2	73.5	84.8	75.5	68.6	74.3	72.2	72.2	72.9	74.3	81.3	78.4	76.0	76.6	73.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-86.99	-39.31	-20.80	-10.30	-6.25	-41.17	-27.03	-46.89	-2.80	Regr. line intercept	-38.78
Regr. line slope	77.92	53.31	43.24	37.25	34.32	50.09	41.75	50.33	26.44	Regr. line slope	61.48
Correlation coefficient	0.70	0.50	0.42	0.34	0.26	0.40	0.35	0.32	0.17	Correlation coefficient	0.57
Average sound level (dBL)	71.2	68.9	67.0	65.3	63.4	60.5	57.7	55.3	50.9	Average sound level (dBA)	86.0
Std. dev. of sound level (dBL)	2.8	2.7	2.6	2.8	3.3	3.2	3.0	4.0	3.8	Std. dev. of sound level (dBA)	2.7
Std. dev. of sound level residuals (dBL)	2.0	2.3	2.4	2.6	3.2	2.9	2.8	3.8	3.7	Std. dev. of sound level residuals (dBA)	2.2
L_{veh} at ref. speed (dBL)	71.1	68.9	66.9	65.3	63.4	60.5	57.7	55.3	50.9	L_{veh} at ref. speed (dBA)	86.0

Table C.28. Sound Level and Speed Regression Data Subject Pavement (innovative grind) on I-94, measured Tuesday, August 18, 2009 50’ microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	46	
Average speed* (km/h [mph])	107.2	[66.6]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	31.46	89.18	32.90	5.35	45.30	14.78	50.69	-32.17	37.10	24.32	25.98	-34.09	-49.32	-38.92	-29.31
Regr. line slope	19.74	-7.97	24.12	34.06	11.18	28.49	10.11	50.90	17.47	24.26	26.34	55.31	61.80	56.50	50.60
Correlation coefficient	0.13	-0.04	0.11	0.20	0.07	0.15	0.07	0.31	0.08	0.14	0.11	0.26	0.38	0.39	0.35
Average sound level (dBL)	71.5	73.0	81.9	74.5	68.0	72.6	71.2	71.2	72.6	73.6	79.4	78.2	76.1	75.8	73.4
Std. dev. of sound level (dBL)	3.4	4.3	5.0	4.0	4.0	4.6	3.2	3.8	5.0	4.0	5.8	5.0	3.8	3.4	3.4
Std. dev. of sound level residuals (dBL)	3.2	4.3	4.8	3.8	3.8	4.5	3.2	3.6	4.9	3.8	5.6	4.8	3.5	3.1	3.0
L_{veh} at ref. speed (dBL)	71.5	73.0	81.9	74.5	68.0	72.6	71.2	71.1	72.6	73.6	79.4	78.2	76.1	75.7	73.4

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-67.10	-23.43	-9.20	-7.31	-14.93	-45.89	-32.86	-39.36	-1.29	Regr. line intercept	-21.96
Regr. line slope	67.87	45.24	37.23	35.55	38.40	52.23	44.43	46.40	25.73	Regr. line slope	52.91
Correlation coefficient	0.59	0.41	0.32	0.27	0.25	0.37	0.33	0.27	0.15	Correlation coefficient	0.46
Average sound level (dBL)	70.7	68.4	66.4	64.9	63.0	60.2	57.3	54.8	51.0	Average sound level (dBA)	85.5
Std. dev. of sound level (dBL)	2.7	2.6	2.7	3.1	3.6	3.3	3.2	4.0	4.0	Std. dev. of sound level (dBA)	2.7
Std. dev. of sound level residuals (dBL)	2.1	2.3	2.5	3.0	3.5	3.0	3.0	3.8	3.9	Std. dev. of sound level residuals (dBA)	2.4
L_{veh} at ref. speed (dBL)	70.6	68.4	66.4	64.8	63.0	60.1	57.3	54.8	50.9	L_{veh} at ref. speed (dBA)	85.4

Appendix D Sound Level and Speed Regression Data for Differences of Paired Observations

This appendix contains the sound level and speed regression data for the paired measurements at MnROAD. The differences are evaluated to generate the sample set in the following manner:

- **Cell 7 vs. Cell 8**: is the level of the vehicle at cell 7 subtracted from the level of the same vehicle at cell 8, so positive values indicate that it is louder at cell 8 (conventional grind) where negative values indicate that it is louder at cell 7 (innovative grind).

- **Cell 7 vs. Cell 97**: is the level of the vehicle at cell 7 subtracted from the level of the same vehicle at cell 97, so positive values indicate that it is louder at cell 97 (transverse tine) where negative values indicate that it is louder at cell 7 (innovative grind).

- **Cell 8 vs. Cell 97**: is the level of the vehicle at cell 8 subtracted from the level of the same vehicle at cell 97, so positive values indicate that it is louder at cell 97 (transverse tine) where negative values indicate that it is louder at cell 8 (conventional grind).

Refer to the topic heading of Data Analysis in Chapter 6 for explanations of the regression parameters. Decibel values are reported in each 1/3 octave-band as linear-weighted or unweighted decibels (dBL) and are reported for the overall sound level as A-weighted decibels (dBA). Speeds are reported in both kilometers per hour and miles per hour.

Table D.1. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 8 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High	
Reference speed (km/h [mph])	115	[71.5]
Number of vehicles	49	
Average speed* (km/h [mph])	118.3	[73.5]
St. dev. of speed* (km/h [mph])	1.1	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-21.37	-18.72	-41.74	-19.28	-25.05	31.51	5.96	30.65	-23.73	-15.80	-22.95	-1.44	-14.90	-11.81	-26.37
Regr. line slope	9.68	8.38	19.62	8.88	11.80	-15.58	-2.97	-13.95	12.51	8.84	12.11	2.33	8.95	7.48	14.49
Correlation coefficient	0.06	0.06	0.13	0.07	0.10	-0.17	-0.03	-0.15	0.14	0.14	0.17	0.03	0.10	0.09	0.21
Average sound level (dBL)	-1.3	-1.3	-1.1	-0.9	-0.6	-0.8	-0.2	1.7	2.2	2.5	2.1	3.4	3.7	3.7	3.7
Std. dev. of sound level (dBL)	4.5	4.0	4.5	3.9	3.5	2.7	3.4	2.6	2.5	1.8	2.1	2.3	2.6	2.4	2.0
Std. dev. of sound level residuals (dBL)	4.5	4.0	4.5	3.9	3.5	2.6	3.4	2.6	2.5	1.8	2.0	2.3	2.5	2.4	2.0
L_{veh} at ref. speed (dBL)	-1.4	-1.4	-1.3	-1.0	-0.7	-0.6	-0.2	1.9	2.1	2.4	2.0	3.4	3.5	3.6	3.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-61.80	-43.40	-31.69	6.59	25.47	21.70	23.65	37.75	23.79	Regr. line intercept	-25.37
Regr. line slope	31.22	21.59	15.00	-3.75	-12.58	-10.85	-12.13	-18.60	-11.63	Regr. line slope	13.49
Correlation coefficient	0.35	0.26	0.21	-0.06	-0.18	-0.19	-0.21	-0.30	-0.22	Correlation coefficient	0.26
Average sound level (dBL)	2.9	1.3	-0.6	-1.2	-0.6	-0.8	-1.5	-0.8	-0.3	Average sound level (dBA)	2.6
Std. dev. of sound level (dBL)	2.6	2.4	2.0	1.8	2.0	1.7	1.6	1.8	1.6	Std. dev. of sound level (dBA)	1.5
Std. dev. of sound level residuals (dBL)	2.5	2.3	2.0	1.8	2.0	1.7	1.6	1.7	1.5	Std. dev. of sound level residuals (dBA)	1.4
L_{veh} at ref. speed (dBL)	2.5	1.1	-0.8	-1.1	-0.4	-0.6	-1.4	-0.6	-0.2	L_{veh} at ref. speed (dBA)	2.4

Table D.2. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 8 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	2
Average speed* (km/h [mph])	114.6 [71.2]
St. dev. of speed* (km/h [mph])	1.0 [0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	-3.3	3.2	-1.6	-0.6	-2.7	0.8	1.5	3.3	0.8	0.5	0.9	2.6	4.1	-1.0	1.0
Std. dev. of sound level (dBL)	9.7	2.5	5.4	0.1	2.7	0.6	1.3	2.6	3.0	2.6	4.1	3.5	0.4	2.6	0.3
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	-0.3	1.6	0.6	1.0	1.0	-0.1	-1.7	-1.2	1.0	Average sound level (dBA)	-0.4
Std. dev. of sound level (dBL)	0.2	0.6	1.6	1.1	0.3	1.6	1.3	3.0	3.4	Std. dev. of sound level (dBA)	2.6
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table D.3. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 8 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	7
Average speed* (km/h [mph])	107.5 [66.8]
St. dev. of speed* (km/h [mph])	1.0 [0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	230.22	43.74	63.72	-87.66	-44.31	-119.34	-197.16	-183.39	-115.43	-195.54	-166.53	-157.99	-134.90	-141.68	-325.01
Regr. line slope	-113.19	-21.22	-30.98	43.72	22.56	59.42	98.12	90.35	57.31	97.16	83.12	78.05	67.04	68.85	158.98
Correlation coefficient	-0.43	-0.17	-0.18	0.36	0.19	0.39	0.66	0.66	0.60	0.68	0.33	0.39	0.38	0.27	0.55
Average sound level (dBL)	0.3	0.6	0.8	1.2	1.5	1.4	2.2	0.2	1.0	1.8	2.3	0.6	1.3	-1.8	-2.0
Std. dev. of sound level (dBL)	5.3	2.4	3.5	2.4	2.4	3.0	3.0	2.7	1.9	2.9	5.0	4.1	3.6	5.0	5.8
Std. dev. of sound level residuals (dBL)	4.8	2.4	3.4	2.3	2.4	2.8	2.2	2.1	1.5	2.1	4.7	3.7	3.3	4.8	4.9
L_{veh} at ref. speed (dBL)	0.5	0.7	0.8	1.1	1.5	1.2	2.0	0.0	0.9	1.6	2.2	0.4	1.1	-2.0	-2.4

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-340.08	-337.51	-342.22	-400.63	-430.63	-470.24	-525.90	-591.94	-460.98	Regr. line intercept	-132.17
Regr. line slope	166.87	165.39	167.51	196.04	211.12	230.01	256.72	289.33	225.29	Regr. line slope	65.02
Correlation coefficient	0.50	0.50	0.44	0.48	0.47	0.48	0.50	0.55	0.47	Correlation coefficient	0.40
Average sound level (dBL)	-1.1	-1.5	-1.9	-2.4	-1.7	-3.0	-4.4	-4.1	-3.3	Average sound level (dBA)	-0.1
Std. dev. of sound level (dBL)	6.7	6.7	7.6	8.3	9.0	9.7	10.2	10.6	9.6	Std. dev. of sound level (dBA)	3.2
Std. dev. of sound level residuals (dBL)	5.7	5.8	6.8	7.3	8.0	8.5	8.8	8.9	8.4	Std. dev. of sound level residuals (dBA)	3.0
L_{veh} at ref. speed (dBL)	-1.4	-1.9	-2.3	-2.8	-2.2	-3.5	-4.9	-4.8	-3.8	L_{veh} at ref. speed (dBA)	-0.2

Table D.4. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 8 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	9
Average speed* (km/h [mph])	109.1 [67.8]
St. dev. of speed* (km/h [mph])	1.0 [0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	334.80	73.19	130.76	-77.86	-2.23	-95.44	-153.61	-195.85	-142.99	-207.28	-202.45	-185.63	-112.25	-160.15	-279.77
Regr. line slope	-164.55	-35.33	-64.05	38.58	1.38	47.46	76.37	96.55	70.64	102.48	100.35	91.60	56.02	77.80	136.63
Correlation coefficient	-0.53	-0.29	-0.33	0.34	0.01	0.33	0.54	0.70	0.67	0.72	0.41	0.46	0.34	0.33	0.50
Average sound level (dBL)	-0.5	1.2	0.3	0.8	0.6	1.3	2.0	0.9	0.9	1.5	2.0	1.0	1.9	-1.6	-1.4
Std. dev. of sound level (dBL)	5.8	2.3	3.6	2.1	2.3	2.7	2.6	2.6	2.0	2.7	4.6	3.7	3.1	4.5	5.1
Std. dev. of sound level residuals (dBL)	4.2	2.1	2.9	2.0	2.1	2.4	1.9	1.8	1.3	1.8	4.1	3.2	2.9	4.2	4.2
L_{veh} at ref. speed (dBL)	0.9	1.5	0.8	0.4	0.6	0.9	1.4	0.1	0.4	0.7	1.2	0.3	1.4	-2.3	-2.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-300.18	-285.72	-277.27	-334.08	-372.13	-433.33	-477.32	-558.48	-449.48	Regr. line intercept	-151.77
Regr. line slope	146.87	139.82	135.41	163.16	182.07	211.52	232.39	272.37	219.44	Regr. line slope	74.41
Correlation coefficient	0.47	0.45	0.38	0.42	0.43	0.47	0.49	0.55	0.49	Correlation coefficient	0.47
Average sound level (dBL)	-0.9	-0.8	-1.4	-1.6	-1.1	-2.3	-3.8	-3.5	-2.3	Average sound level (dBA)	-0.2
Std. dev. of sound level (dBL)	5.8	5.8	6.6	7.2	7.8	8.4	8.9	9.3	8.4	Std. dev. of sound level (dBA)	2.9
Std. dev. of sound level residuals (dBL)	5.0	5.0	5.9	6.3	6.9	7.4	7.7	7.7	7.3	Std. dev. of sound level residuals (dBA)	2.6
L_{veh} at ref. speed (dBL)	-2.1	-2.0	-2.5	-3.0	-2.6	-4.1	-5.7	-5.7	-4.2	L_{veh} at ref. speed (dBA)	-0.8

Table D.5. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High
Reference speed (km/h [mph])	115 [71.5]
Number of vehicles	49
Average speed* (km/h [mph])	118.3 [73.5]
St. dev. of speed* (km/h [mph])	1.1 [0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-29.79	8.09	-51.66	-5.07	8.79	23.47	-22.53	53.84	45.43	-4.77	17.11	26.62	31.66	-0.94	11.37
Regr. line slope	14.99	-3.13	25.83	3.70	-3.08	-9.95	13.51	-22.98	-18.11	5.76	-4.71	-8.82	-11.17	4.30	-1.21
Correlation coefficient	0.11	-0.02	0.15	0.02	-0.02	-0.09	0.11	-0.21	-0.15	0.07	-0.04	-0.08	-0.10	0.04	-0.02
Average sound level (dBL)	1.3	1.6	1.9	2.6	2.4	2.9	5.5	6.2	7.9	7.2	7.4	8.3	8.5	8.0	8.9
Std. dev. of sound level (dBL)	4.1	4.2	4.9	4.3	3.7	3.2	3.5	3.2	3.5	2.5	3.4	3.2	3.2	3.1	2.2
Std. dev. of sound level residuals (dBL)	4.1	4.2	4.8	4.3	3.7	3.2	3.5	3.1	3.4	2.5	3.4	3.2	3.2	3.1	2.2
L_{veh} at ref. speed (dBL)	1.1	1.6	1.6	2.5	2.4	3.0	5.3	6.5	8.1	7.1	7.4	8.4	8.6	7.9	8.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-79.97	-56.74	-40.87	-13.08	0.71	-7.86	-8.64	18.13	-8.37	Regr. line intercept	-9.69
Regr. line slope	43.95	31.75	23.18	8.86	1.90	6.61	6.92	-5.95	7.48	Regr. line slope	8.75
Correlation coefficient	0.33	0.26	0.20	0.10	0.02	0.08	0.10	-0.08	0.11	Correlation coefficient	0.11
Average sound level (dBL)	11.1	9.1	7.2	5.3	4.7	5.8	5.7	5.8	7.1	Average sound level (dBA)	8.5
Std. dev. of sound level (dBL)	3.9	3.5	3.4	2.7	2.6	2.5	2.0	2.2	2.0	Std. dev. of sound level (dBA)	2.3
Std. dev. of sound level residuals (dBL)	3.7	3.3	3.3	2.6	2.6	2.5	2.0	2.2	2.0	Std. dev. of sound level residuals (dBA)	2.3
L_{veh} at ref. speed (dBL)	10.6	8.7	6.9	5.2	4.6	5.8	5.6	5.9	7.1	L_{veh} at ref. speed (dBA)	8.3

Table D.6. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	2
Average speed* (km/h [mph])	114.6 [71.2]
St. dev. of speed* (km/h [mph])	1.0 [0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	-3.1	0.5	1.1	2.0	2.1	2.0	8.4	11.5	5.2	7.0	3.6	11.6	9.2	1.3	6.3
Std. dev. of sound level (dBL)	4.6	6.9	5.3	2.6	0.6	0.4	1.3	5.1	2.8	0.8	5.5	1.1	4.0	6.4	0.4
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	6.5	6.6	5.5	6.6	6.9	6.2	6.8	7.1	9.5	Average sound level (dBA)	3.2
Std. dev. of sound level (dBL)	1.6	1.9	4.7	4.8	3.6	3.0	4.6	2.3	1.3	Std. dev. of sound level (dBA)	4.4
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table D.7. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	7	
Average speed* (km/h [mph])	107.5	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-202.37	-486.38	67.50	61.19	-67.45	-25.99	-118.19	-50.78	-148.46	-76.76	331.87	455.45	93.41	136.43	60.41
Regr. line slope	101.09	240.59	-34.10	-26.57	36.73	15.64	62.75	28.31	76.52	41.44	-160.37	-222.69	-41.09	-64.55	-26.57
Correlation coefficient	0.52	0.64	-0.14	-0.18	0.22	0.11	0.41	0.17	0.35	0.31	-0.71	-0.64	-0.23	-0.41	-0.13
Average sound level (dBL)	3.0	2.4	-1.8	7.2	7.2	5.8	9.3	6.7	7.0	7.4	6.1	3.1	9.9	5.3	6.4
Std. dev. of sound level (dBL)	3.9	7.6	4.9	3.0	3.3	2.8	3.1	3.3	4.4	2.7	4.5	7.0	3.6	3.2	4.1
Std. dev. of sound level residuals (dBL)	3.3	5.9	4.8	2.9	3.3	2.8	2.8	3.3	4.1	2.6	3.2	5.4	3.5	2.9	4.1
L_{veh} at ref. speed (dBL)	2.8	1.9	-1.7	7.3	7.1	5.8	9.1	6.7	6.8	7.3	6.4	3.5	10.0	5.4	6.5

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-128.81	18.51	31.08	-6.58	36.22	40.02	73.37	35.48	64.07	Regr. line intercept	213.56
Regr. line slope	67.65	-5.83	-11.97	5.96	-14.95	-16.18	-32.80	-14.04	-27.33	Regr. line slope	-102.61
Correlation coefficient	0.65	-0.08	-0.18	0.07	-0.12	-0.15	-0.30	-0.13	-0.25	Correlation coefficient	-0.82
Average sound level (dBL)	8.6	6.7	6.8	5.5	5.9	7.1	6.7	7.0	8.6	Average sound level (dBA)	5.1
Std. dev. of sound level (dBL)	2.1	1.5	1.3	1.7	2.5	2.1	2.2	2.2	2.2	Std. dev. of sound level (dBA)	2.5
Std. dev. of sound level residuals (dBL)	1.6	1.5	1.3	1.6	2.5	2.1	2.1	2.1	2.1	Std. dev. of sound level residuals (dBA)	1.4
L_{veh} at ref. speed (dBL)	8.5	6.7	6.8	5.5	5.9	7.2	6.8	7.0	8.6	L_{veh} at ref. speed (dBA)	5.3

Table D.8. Sound Level and Speed Regression Data Pavement Cell 7 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High
Reference speed (km/h [mph])	107 [66.5]
Number of vehicles	9
Average speed* (km/h [mph])	109.1 [67.8]
St. dev. of speed* (km/h [mph])	1.0 [0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-114.15	-330.21	132.93	16.96	-50.38	-27.75	-119.98	-113.06	-168.51	-54.50	213.85	385.70	137.64	29.83	58.50
Regr. line slope	56.83	163.01	-65.80	-5.36	27.68	16.04	63.34	59.31	85.93	30.35	-102.24	-186.86	-62.75	-12.48	-25.56
Correlation coefficient	0.28	0.43	-0.27	-0.04	0.18	0.12	0.44	0.32	0.41	0.24	-0.43	-0.57	-0.34	-0.07	-0.13
Average sound level (dBL)	1.7	2.0	-1.1	6.0	6.0	4.9	9.1	7.8	6.6	7.3	5.5	4.9	9.8	4.4	6.4
Std. dev. of sound level (dBL)	3.8	7.0	4.6	2.7	2.9	2.4	2.7	3.4	3.9	2.4	4.4	6.1	3.4	3.6	3.6
Std. dev. of sound level residuals (dBL)	2.9	5.1	4.2	2.5	2.8	2.4	2.4	2.8	3.6	2.2	2.8	4.7	3.1	2.5	3.5
L_{veh} at ref. speed (dBL)	1.2	0.6	-0.6	6.1	5.8	4.8	8.6	7.3	5.9	7.1	6.4	6.5	10.3	4.5	6.6

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-90.42	43.46	92.44	61.84	82.62	77.81	128.71	64.26	74.94	Regr. line intercept	125.38
Regr. line slope	48.38	-18.07	-42.19	-27.52	-37.56	-34.79	-59.86	-28.11	-32.48	Regr. line slope	-59.23
Correlation coefficient	0.48	-0.23	-0.39	-0.23	-0.28	-0.31	-0.45	-0.26	-0.31	Correlation coefficient	-0.41
Average sound level (dBL)	8.2	6.6	6.5	5.8	6.1	6.9	6.7	7.0	8.8	Average sound level (dBA)	4.7
Std. dev. of sound level (dBL)	1.9	1.4	2.0	2.2	2.5	2.1	2.5	2.0	1.9	Std. dev. of sound level (dBA)	2.7
Std. dev. of sound level residuals (dBL)	1.4	1.3	1.1	1.4	2.2	1.8	1.8	1.8	1.8	Std. dev. of sound level residuals (dBA)	1.2
L_{veh} at ref. speed (dBL)	7.8	6.8	6.8	6.0	6.4	7.2	7.2	7.2	9.0	L_{veh} at ref. speed (dBA)	5.2

Table D.9. Sound Level and Speed Regression Data Pavement Cell 8 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 1 (cars)

Road speed category	High
Reference speed (km/h [mph])	115 [71.5]
Number of vehicles	49
Average speed* (km/h [mph])	118.3 [73.5]
St. dev. of speed* (km/h [mph])	1.1 [0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-8.42	26.80	-9.91	14.21	33.85	-8.04	-28.49	23.19	69.15	11.02	40.06	28.05	46.56	10.87	37.74
Regr. line slope	5.31	-11.51	6.20	-5.18	-14.88	5.63	16.47	-9.03	-30.62	-3.09	-16.81	-11.15	-20.13	-3.18	-15.70
Correlation coefficient	0.04	-0.08	0.04	-0.04	-0.10	0.04	0.12	-0.08	-0.29	-0.04	-0.20	-0.12	-0.23	-0.04	-0.19
Average sound level (dBL)	2.6	2.9	2.9	3.5	3.0	3.6	5.7	4.5	5.7	4.6	5.2	4.9	4.8	4.3	5.2
Std. dev. of sound level (dBL)	4.1	4.0	4.3	4.1	4.3	3.8	4.0	3.4	3.0	2.5	2.4	2.7	2.5	2.6	2.4
Std. dev. of sound level residuals (dBL)	4.1	4.0	4.3	4.1	4.3	3.8	3.9	3.4	2.9	2.5	2.4	2.7	2.5	2.6	2.3
L_{veh} at ref. speed (dBL)	2.5	3.1	2.9	3.5	3.2	3.6	5.5	4.6	6.0	4.7	5.4	5.1	5.1	4.3	5.4

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	-18.17	-13.34	-9.17	-19.67	-24.77	-29.56	-32.29	-19.62	-32.16	Regr. line intercept	15.68
Regr. line slope	12.73	10.17	8.17	12.61	14.48	17.46	19.05	12.65	19.11	Regr. line slope	-4.73
Correlation coefficient	0.13	0.12	0.08	0.15	0.20	0.20	0.25	0.16	0.24	Correlation coefficient	-0.08
Average sound level (dBL)	8.2	7.7	7.8	6.5	5.2	6.6	7.2	6.6	7.5	Average sound level (dBA)	5.9
Std. dev. of sound level (dBL)	2.8	2.5	2.9	2.4	2.1	2.5	2.2	2.2	2.3	Std. dev. of sound level (dBA)	1.7
Std. dev. of sound level residuals (dBL)	2.8	2.5	2.9	2.4	2.1	2.4	2.1	2.2	2.3	Std. dev. of sound level residuals (dBA)	1.7
L_{veh} at ref. speed (dBL)	8.1	7.6	7.7	6.3	5.1	6.4	7.0	6.4	7.2	L_{veh} at ref. speed (dBA)	5.9

Table D.10. Sound Level and Speed Regression Data Pavement Cell 8 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2a (dual axle/medium trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	2	
Average speed* (km/h [mph])	114.6	[71.2]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept															
Regr. line slope															
Correlation coefficient															
Average sound level (dBL)	0.2	-2.7	2.6	2.6	4.8	1.1	7.0	8.2	4.5	6.6	2.7	9.0	5.2	2.2	5.3
Std. dev. of sound level (dBL)	5.1	4.4	0.1	2.5	2.1	1.0	2.6	2.5	0.2	3.5	1.4	2.4	3.6	3.8	0.1
Std. dev. of sound level residuals (dBL)															
L_{veh} at ref. speed (dBL)															

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept										Regr. line intercept	
Regr. line slope										Regr. line slope	
Correlation coefficient										Correlation coefficient	
Average sound level (dBL)	6.8	5.0	4.9	5.6	5.9	6.2	8.5	8.3	8.5	Average sound level (dBA)	3.6
Std. dev. of sound level (dBL)	1.8	1.3	3.1	3.7	3.3	4.7	5.9	5.3	4.7	Std. dev. of sound level (dBA)	1.8
Std. dev. of sound level residuals (dBL)										Std. dev. of sound level residuals (dBA)	
L_{veh} at ref. speed (dBL)										L_{veh} at ref. speed (dBA)	

Table D.11. Sound Level and Speed Regression Data Pavement Cell 8 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2b (multi-axle/heavy trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	7	
Average speed* (km/h [mph])	107.5	[66.8]
St. dev. of speed* (km/h [mph])	1.0	[0.7]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-432.59	-530.12	3.78	148.85	-23.14	93.35	78.98	132.61	-33.03	118.78	498.39	613.44	228.31	278.11	385.43
Regr. line slope	214.28	261.81	-3.11	-70.29	14.17	-43.78	-35.37	-62.05	19.20	-55.72	-243.49	-300.74	-108.13	-133.40	-185.55
Correlation coefficient	0.79	0.77	-0.01	-0.55	0.09	-0.34	-0.42	-0.31	0.12	-0.32	-0.84	-0.77	-0.41	-0.50	-0.54
Average sound level (dBL)	2.7	1.8	-2.5	6.0	5.6	4.4	7.1	6.6	6.0	5.6	3.7	2.5	8.6	7.1	8.5
Std. dev. of sound level (dBL)	5.5	6.9	4.3	2.6	3.1	2.6	1.7	4.0	3.1	3.4	5.8	7.8	5.3	5.4	6.9
Std. dev. of sound level residuals (dBL)	3.4	4.4	4.3	2.1	3.1	2.4	1.5	3.8	3.1	3.3	3.2	5.0	4.9	4.7	5.8
L_{veh} at ref. speed (dBL)	2.3	1.2	-2.5	6.2	5.6	4.5	7.2	6.7	5.9	5.7	4.3	3.1	8.9	7.4	8.9

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	211.27	356.01	373.30	394.06	466.86	510.26	599.27	627.41	525.05	Regr. line intercept	345.73
Regr. line slope	-99.21	-171.22	-179.48	-190.09	-226.07	-246.19	-289.52	-303.37	-252.62	Regr. line slope	-167.63
Correlation coefficient	-0.38	-0.48	-0.48	-0.42	-0.45	-0.47	-0.52	-0.51	-0.48	Correlation coefficient	-0.73
Average sound level (dBL)	9.7	8.2	8.7	7.9	7.6	10.1	11.1	11.1	11.8	Average sound level (dBA)	5.2
Std. dev. of sound level (dBL)	5.2	7.2	7.6	9.1	10.0	10.5	11.2	11.8	10.5	Std. dev. of sound level (dBA)	4.6
Std. dev. of sound level residuals (dBL)	4.8	6.3	6.7	8.2	8.9	9.3	9.6	10.1	9.2	Std. dev. of sound level residuals (dBA)	3.2
L_{veh} at ref. speed (dBL)	9.9	8.5	9.1	8.3	8.1	10.6	11.7	11.8	12.4	L_{veh} at ref. speed (dBA)	5.6

Table D.12. Sound Level and Speed Regression Data Pavement Cell 8 versus Pavement Cell 97 at MnROAD, measured Saturday, November 7, 2009 25' microphone position, vehicle category 2 (all trucks)

Road speed category	High	
Reference speed (km/h [mph])	107	[66.5]
Number of vehicles	9	
Average speed* (km/h [mph])	109.1	[67.8]
St. dev. of speed* (km/h [mph])	1.0	[0.6]

* Value converted from the logarithm of speed.

Regression parameter	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	325 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz
Regr. line intercept	-448.95	-403.40	2.17	94.82	-48.14	67.70	33.63	82.79	-25.52	152.78	416.30	571.33	249.89	189.98	338.27
Regr. line slope	221.39	198.35	-1.75	-43.94	26.30	-31.42	-13.03	-37.24	15.29	-72.13	-202.59	-278.46	-118.77	-90.28	-162.19
Correlation coefficient	0.81	0.60	-0.01	-0.34	0.18	-0.26	-0.14	-0.19	0.11	-0.42	-0.74	-0.76	-0.46	-0.35	-0.50
Average sound level (dBL)	2.2	0.8	-1.4	5.3	5.4	3.7	7.1	6.9	5.6	5.8	3.5	3.9	7.9	6.0	7.8
Std. dev. of sound level (dBL)	5.1	6.1	3.8	2.4	2.8	2.2	1.7	3.6	2.7	3.2	5.1	6.8	4.8	4.9	6.0
Std. dev. of sound level residuals (dBL)	2.9	3.8	3.8	1.9	2.7	2.1	1.3	3.3	2.7	2.8	2.7	4.3	4.2	4.1	5.0
L_{veh} at ref. speed (dBL)	0.3	-0.9	-1.4	5.6	5.2	3.9	7.2	7.2	5.5	6.4	5.2	6.2	8.9	6.8	9.1

Regression parameter	1.6 kHz	2 kHz	2.5 kHz	3.25 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz	Regression parameter	Overall
Regr. line intercept	209.75	329.18	369.71	395.92	454.74	511.14	606.03	622.74	524.42	Regr. line intercept	277.15
Regr. line slope	-98.49	-157.88	-177.59	-190.68	-219.64	-246.31	-292.25	-300.48	-251.91	Regr. line slope	-133.64
Correlation coefficient	-0.40	-0.47	-0.50	-0.45	-0.47	-0.50	-0.55	-0.54	-0.51	Correlation coefficient	-0.61
Average sound level (dBL)	9.1	7.5	7.8	7.4	7.2	9.2	10.5	10.5	11.1	Average sound level (dBA)	4.8
Std. dev. of sound level (dBL)	4.6	6.2	6.7	8.0	8.7	9.3	9.9	10.4	9.2	Std. dev. of sound level (dBA)	4.1
Std. dev. of sound level residuals (dBL)	4.2	5.4	5.8	7.1	7.7	8.0	8.3	8.8	7.9	Std. dev. of sound level residuals (dBA)	2.7
L_{veh} at ref. speed (dBL)	9.9	8.8	9.3	9.0	9.0	11.3	12.9	13.0	13.2	L_{veh} at ref. speed (dBA)	6.0

APPENDIX AA MnROAD CELLS PARALLEL OBSI RESULTS

On Board Sound Intensity (OBSI)

On board sound intensity (OBSI) test is a dynamic test that records the pavement tire interaction noise at 60 miles per hour and records the noise from the contact patch alone. This unique property is facilitated by a set of sophisticated microphones installed near the contact patch so that the leading microphone captures the leading edge while the trailing microphone captures the trailing edge.

The OBSI analysis is based on the interim protocol adopted by AASHTO in 2008 [2.01]. The OBSI parameter is the logarithmic sum of sound intensity at each of the designated 3^{rd} octave frequencies of 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000 and 5000 Hz.

OBSI = 10 * log — …… Equation A.01

Where SI_i (i=1, 2 , 3, …,12) are sound intensities in dBA at each the 12 third octave frequencies with lowest centered at 400dBA.

The dBA scale is a logarithmic scale of OBSI defined as

SI = log —…… Equation A.02

Where SI_i and SI_0 in watts/m^2 are respectively, the measured sound intensity and the sound intensity at the threshold of human hearing.

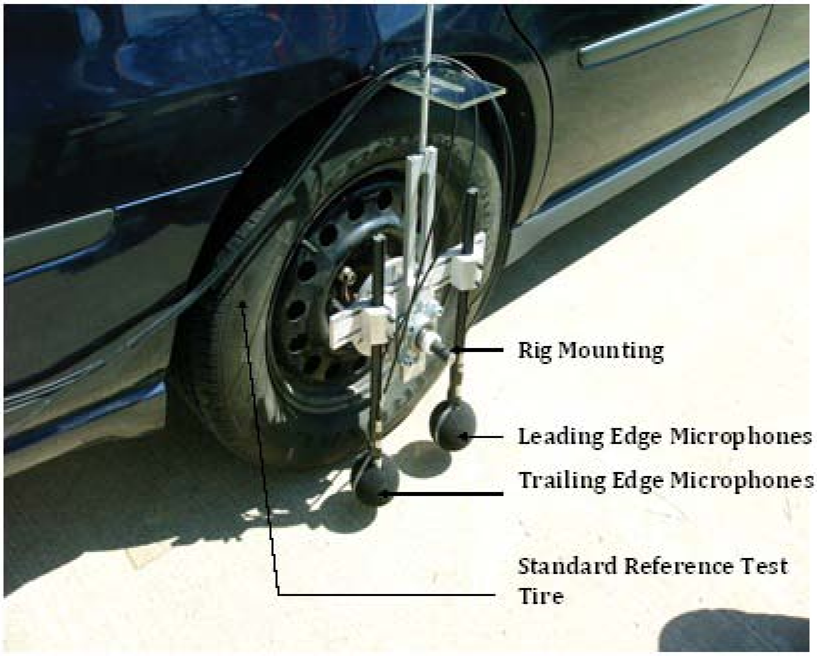


Figure D.1: OBSI Assembly showing SRTT, Mounting Rig, Microphones and Cables

Table D.13: Innovative, Conventional, NovaChip & Transverse Tined MnROAD Cells

Cell	Run Average
NOVACHIP Cell 4 Driving	98.2
NOVACHIP Cell 4 Driving	98.3
NOVACHIP Cell 4 Driving	97.3
Innovative Grind Cell 7 Driving	98.8
Innovative Grind Cell 7 Driving	98.8
Innovative Grind Cell 7 Driving	97.8
Conventional Grind Cell 8 Driving	100.5
Conventional Grind Cell 8 Driving	100.2
Conventional Grind Cell 8 Driving	100.3
Ultimate Grind cell 9 Driving	98.8
Ultimate Grind cell 9 Driving	99.1
Ultimate Grind cell 9 Driving	99.0
Transverse Tine cell 12 Driving	103.7
Transverse Tine cell 12 Driving	103.7
Transverse Tine cell 12 Driving	104.1
NOVACHIP Cell 4 Passing	97.6
NOVACHIP Cell 4 Passing	97.4
NOVACHIP Cell 4 Passing	97.9
Innovative Grind Cell 7 Passing	98.4
Innovative Grind Cell 7 Passing	97.8
Innovative Grind Cell 7 Passing	98.1
Conventional Grind Cell 8 Passing	102.0
Conventional Grind Cell 8 Passing	100.3
Conventional Grind Cell 8 Passing	101.3
Ultimate Grind cell 9 Passing	98.3
Ultimate Grind cell 9 Passing	98.6
Ultimate Grind cell 9 Passing	100.1
Transverse Tine cell 12 Passing	104.4
Transverse Tine cell 12 Passing	103.9
Transverse Tine cell 12 Passing	104.3

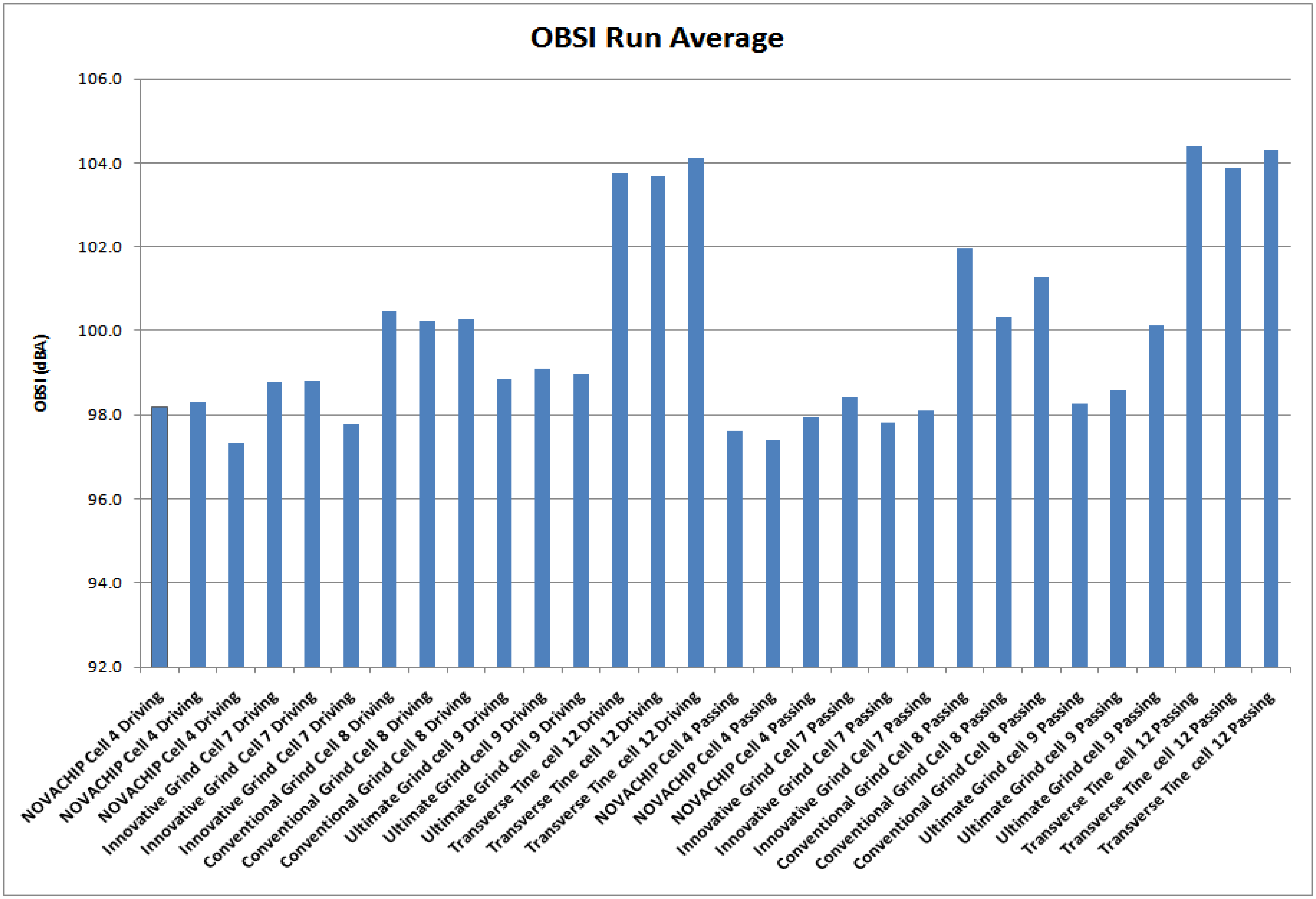


Figure D.2. OBSI Summary for MnROAD Cells

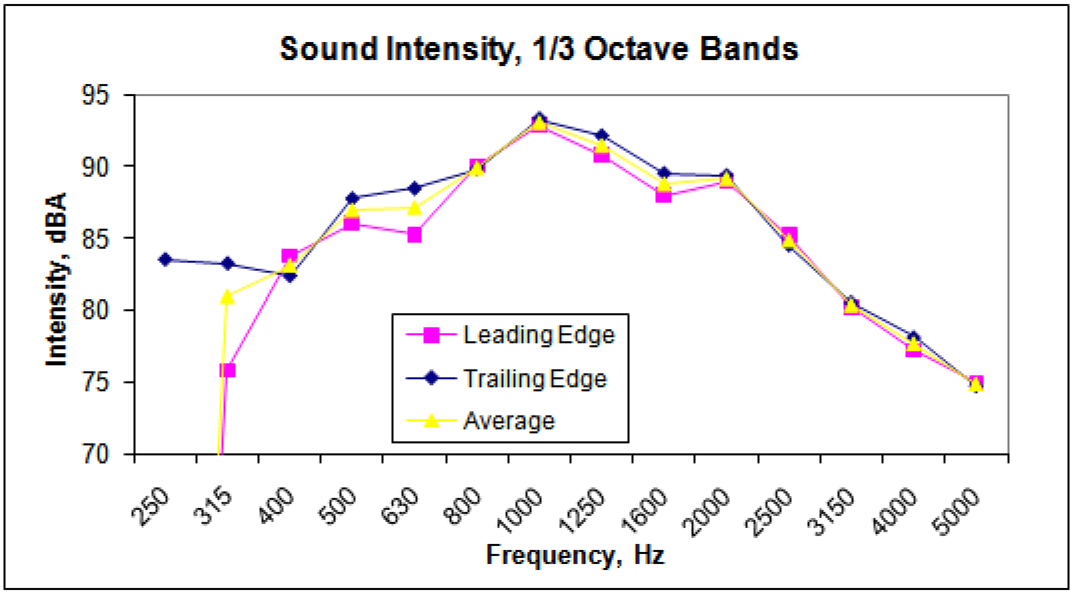


Figure D.3. MnROAD Cell 7 Driving Lane Trial 1

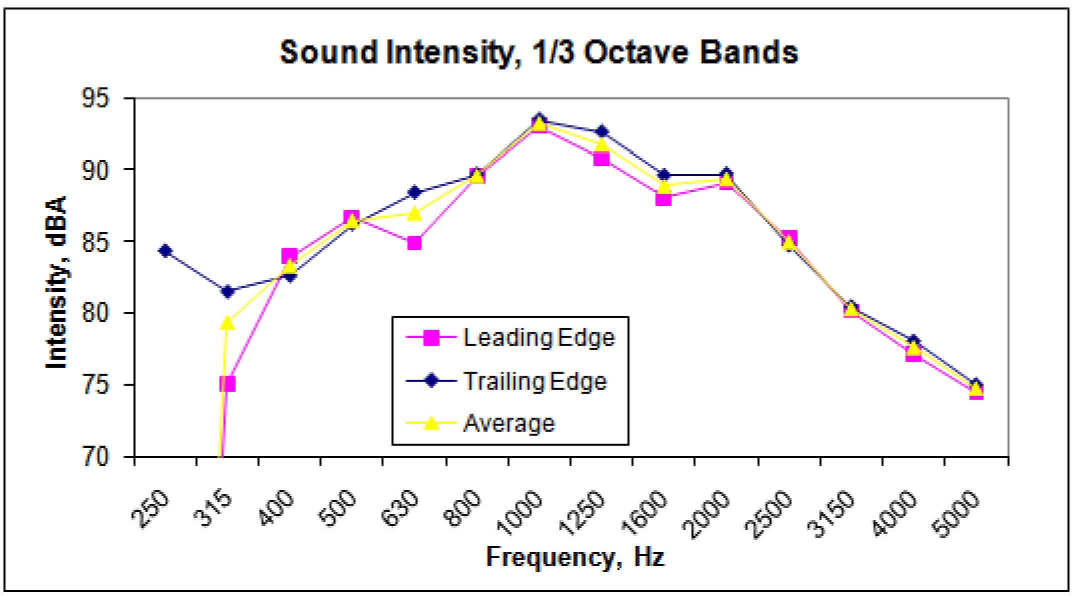


Figure D.4. MnROAD Cell 7 Driving Lane Trial 2

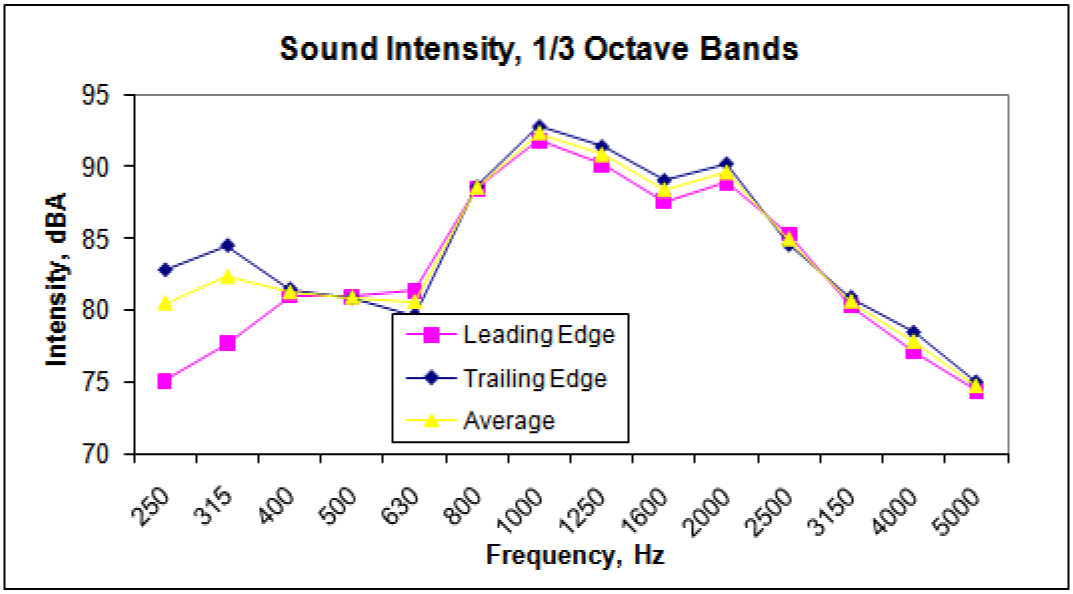


Figure D.5 MnROAD Cell 7 Driving Lane Trial 3

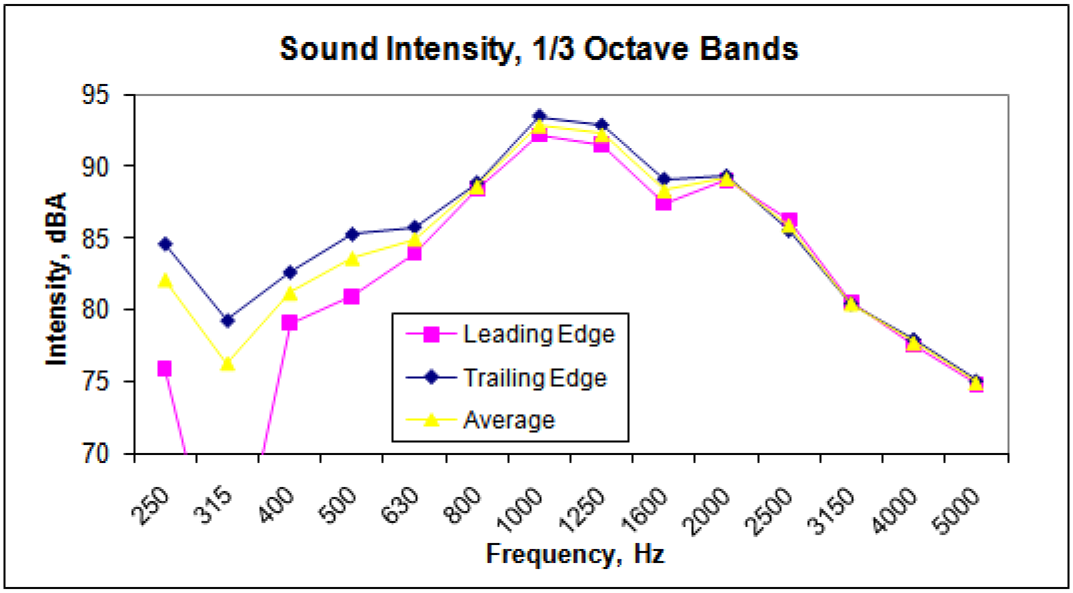


Figure D.6. MnROAD Cell 7 Passing Lane Trial 1

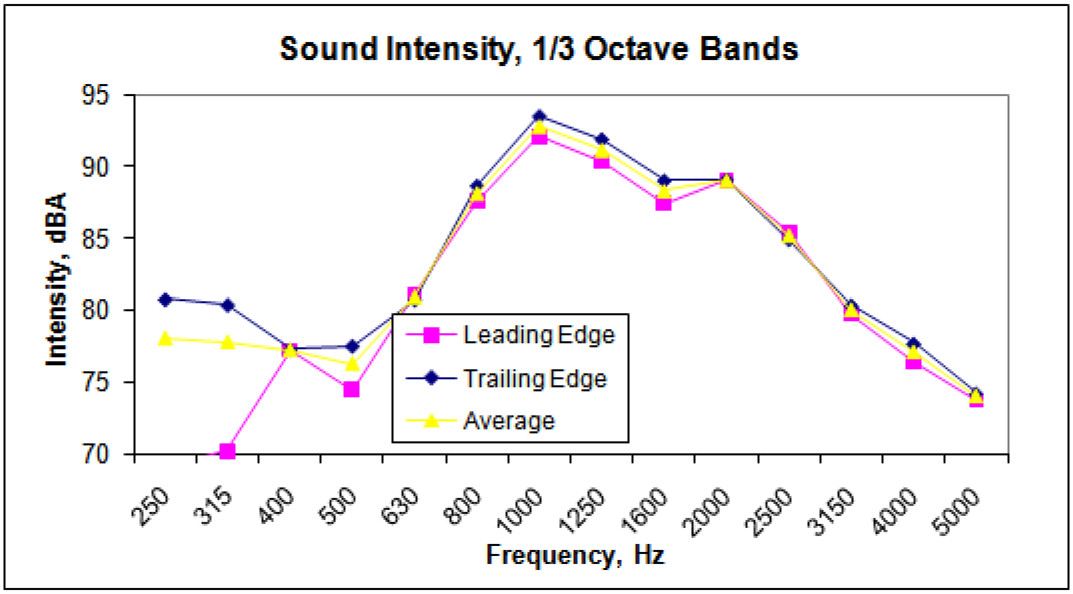


Figure D.7. – MnROAD Cell 7 Passing Lane Trial 2

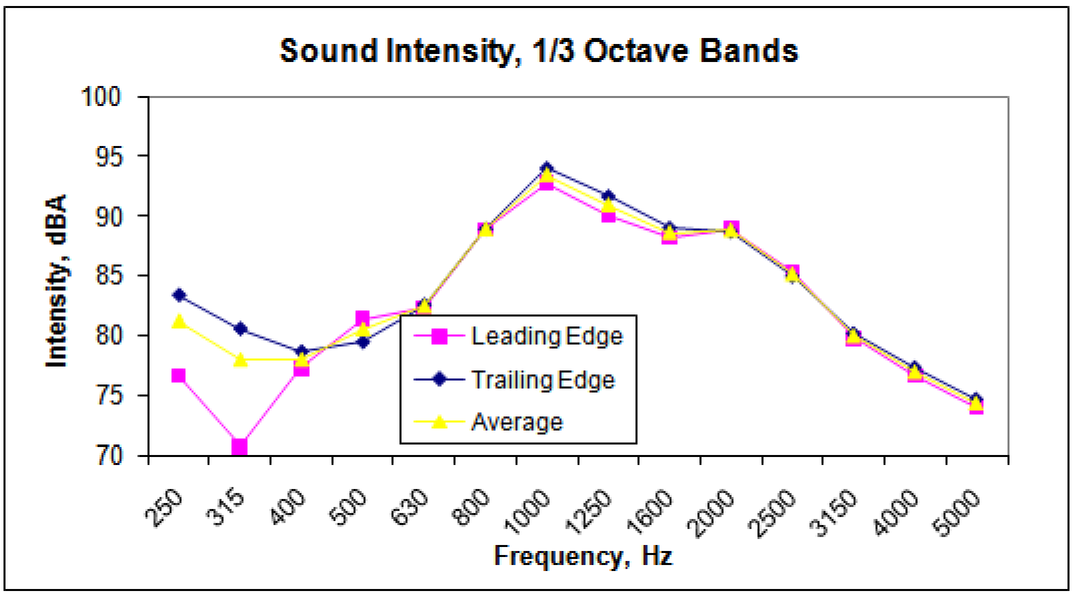


Figure D.8. MnROAD Cell 7 Passing Lane Trial 3

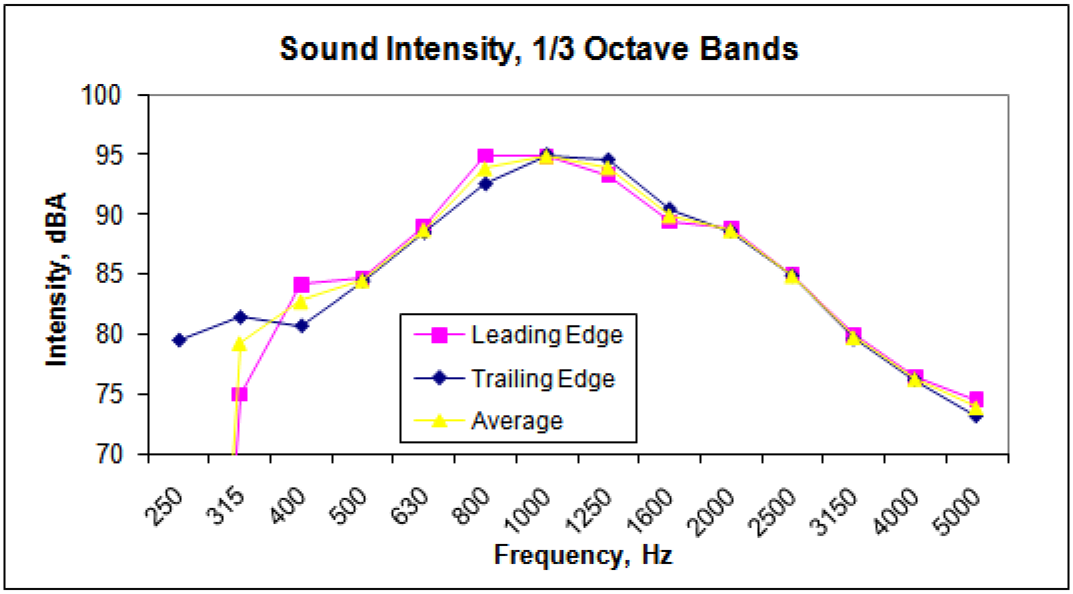


Figure D.9. MnROAD Cell 8 Driving Lane Trial 1

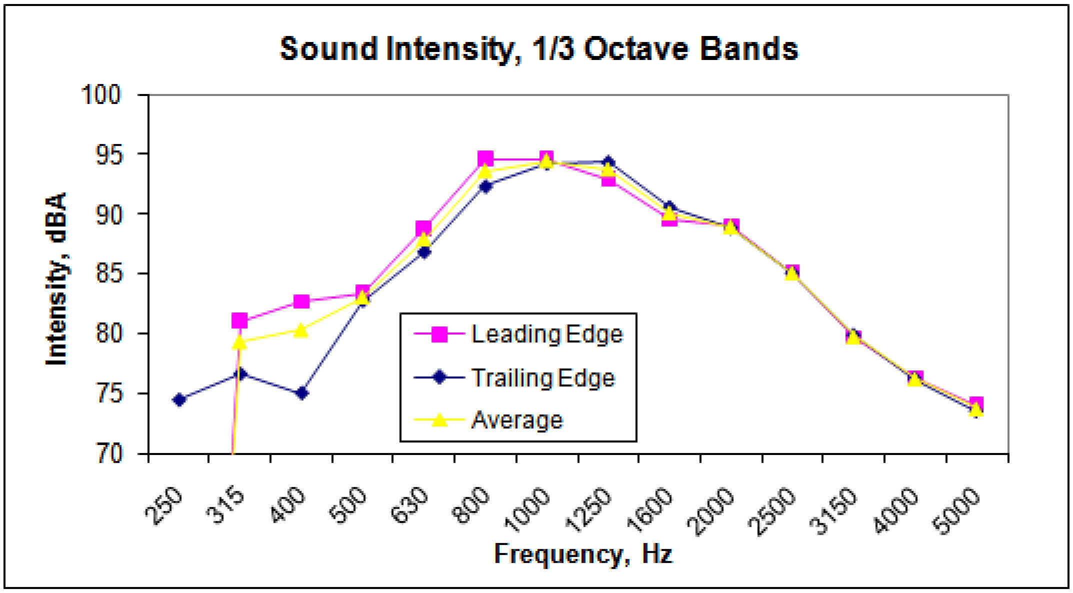


Figure D.10. MnROAD Cell 8 Driving Lane Trial 2

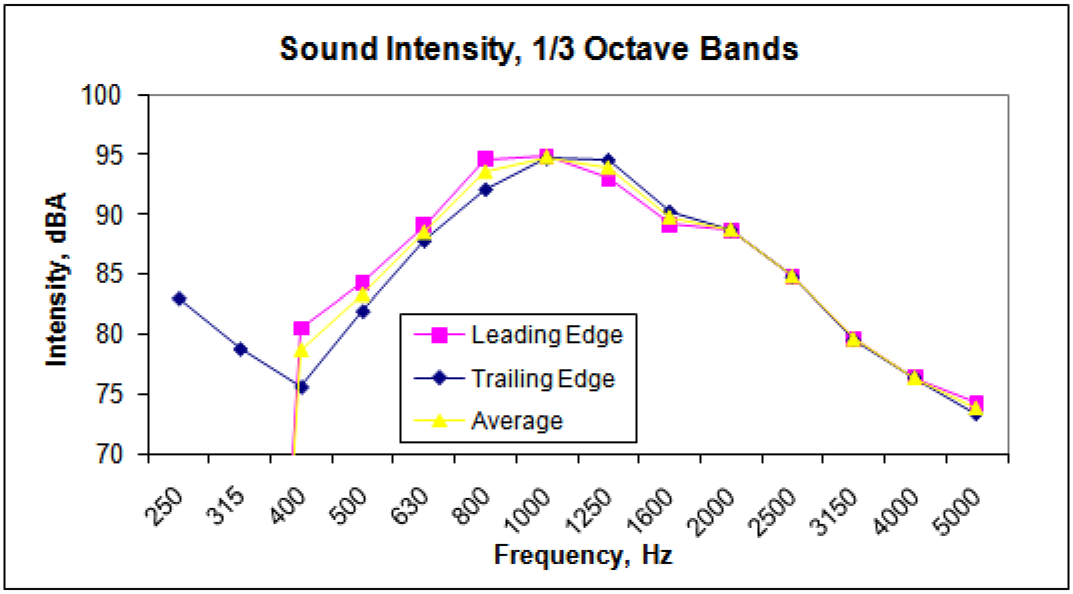


Figure D.11. MnROAD Cell 8 Driving Lane Trial 3

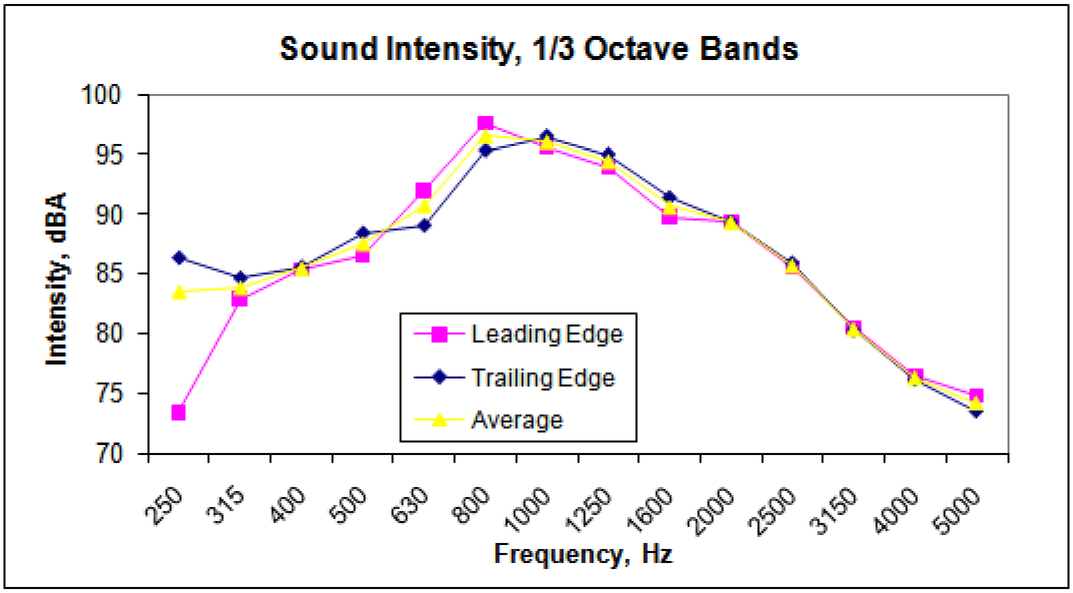


Figure D.12. MnROAD Cell 8 Passing Lane Trial 1

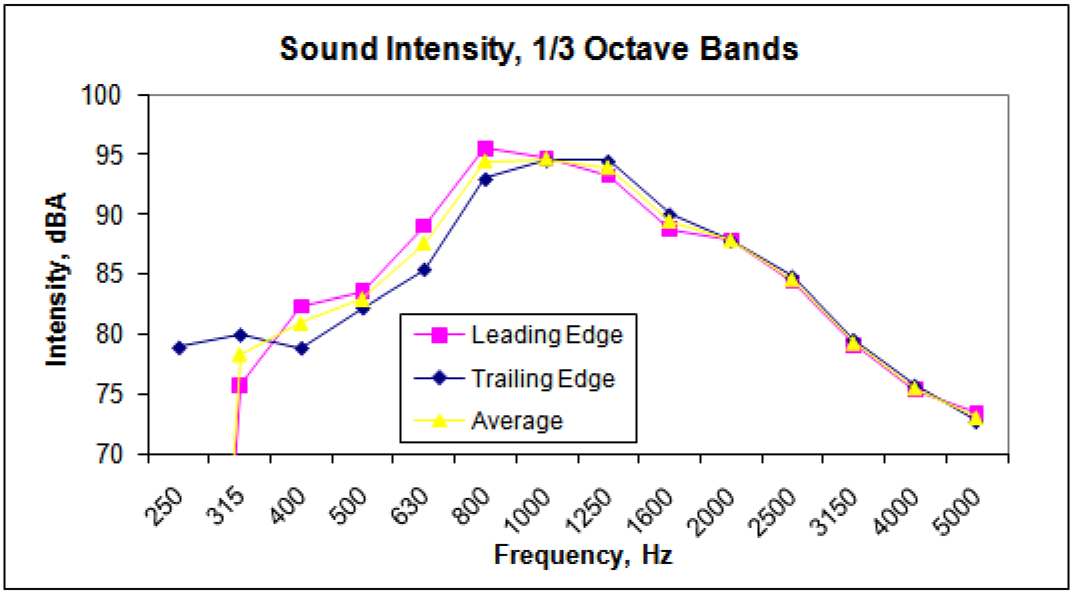


Figure D.13. MnROAD Cell 8 Passing Lane Trial 2

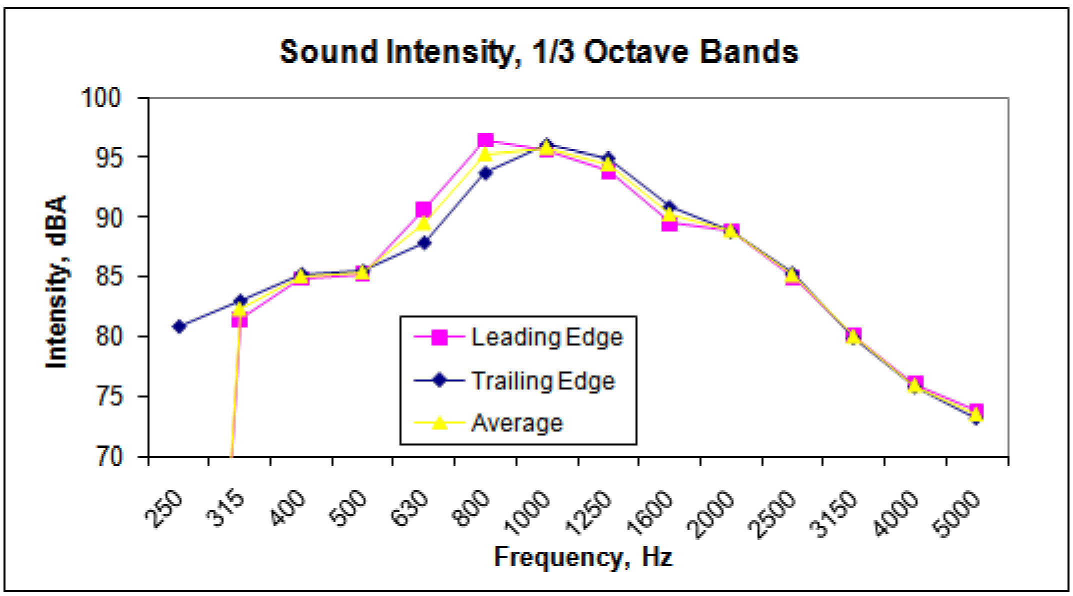


Figure D.14. MnROAD Cell 8 Passing Lane Trial 3

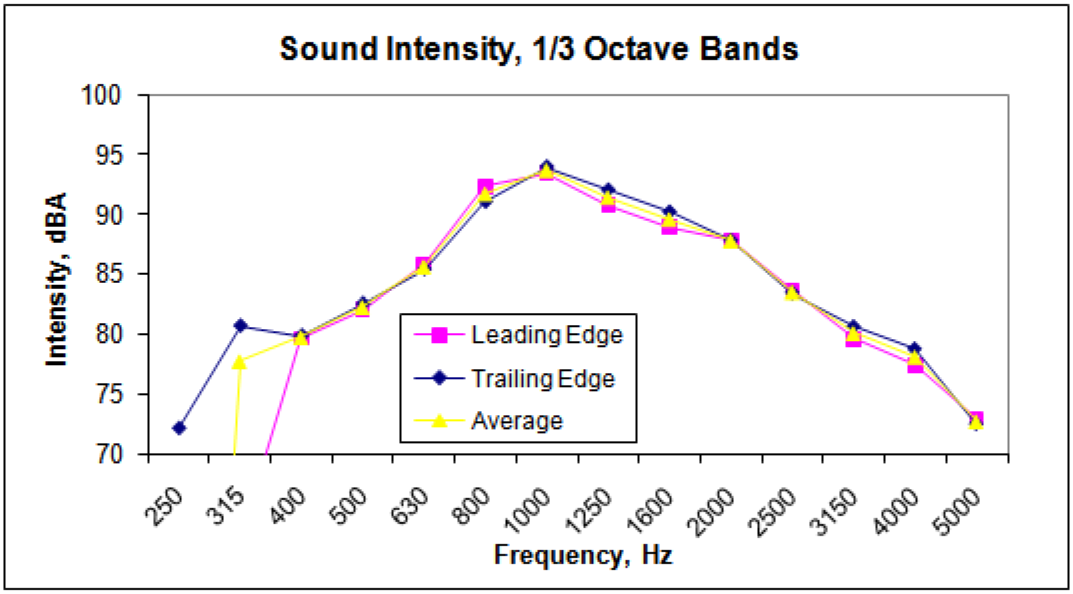


Figure D.15. MnROAD Cell 9 Driving Lane Trial 1

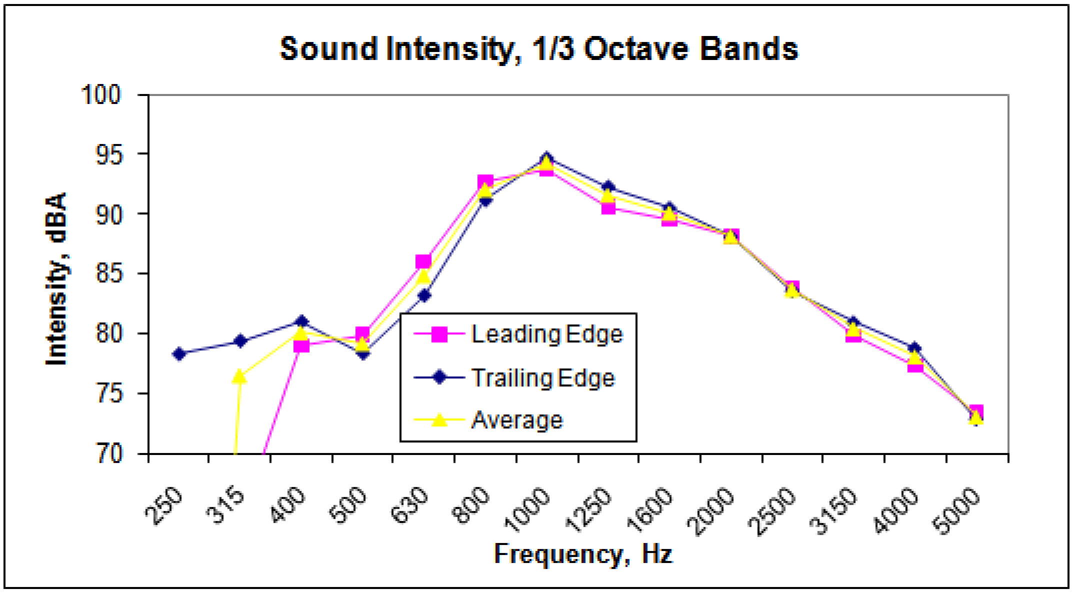


Figure D.16. MnROAD Cell 9 Driving Lane Trial 2

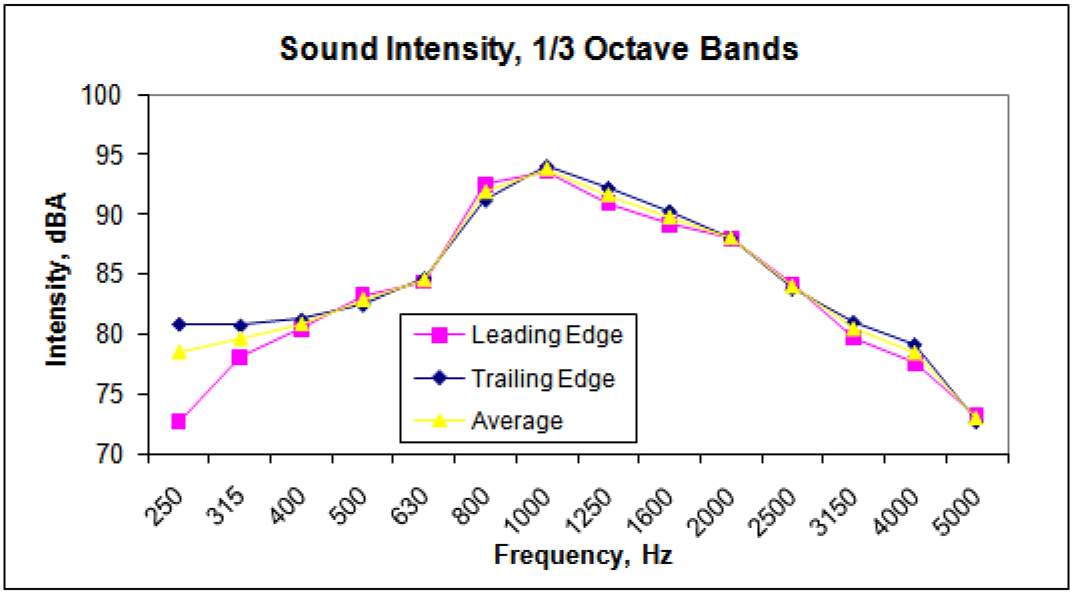


Figure D.16. MnROAD Cell 9 Driving Lane Trial 3

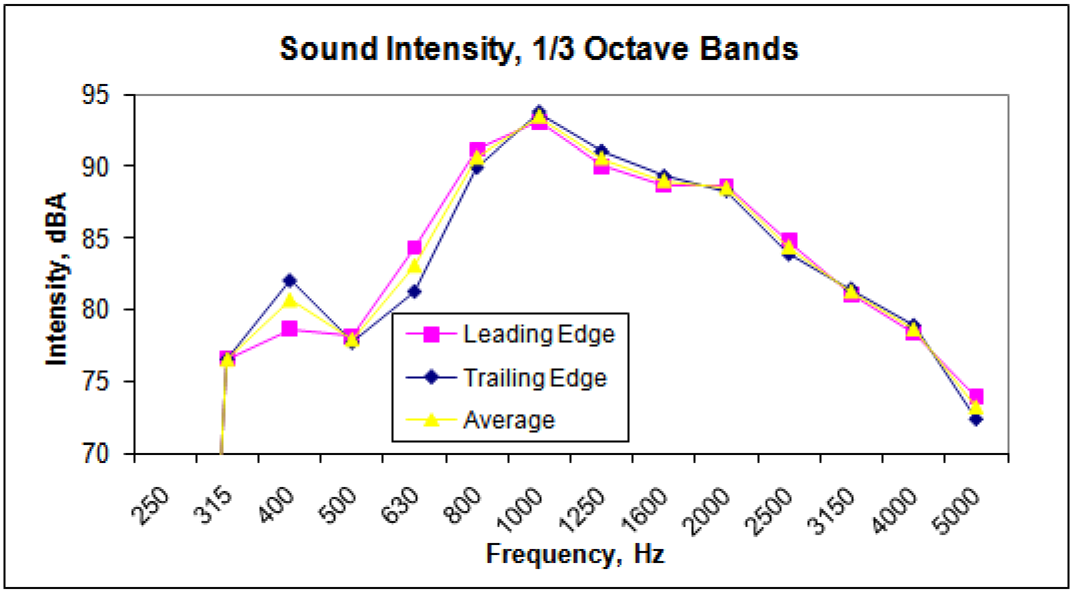


Figure D.17. MnROAD Cell 9 Passing Lane Trial 1

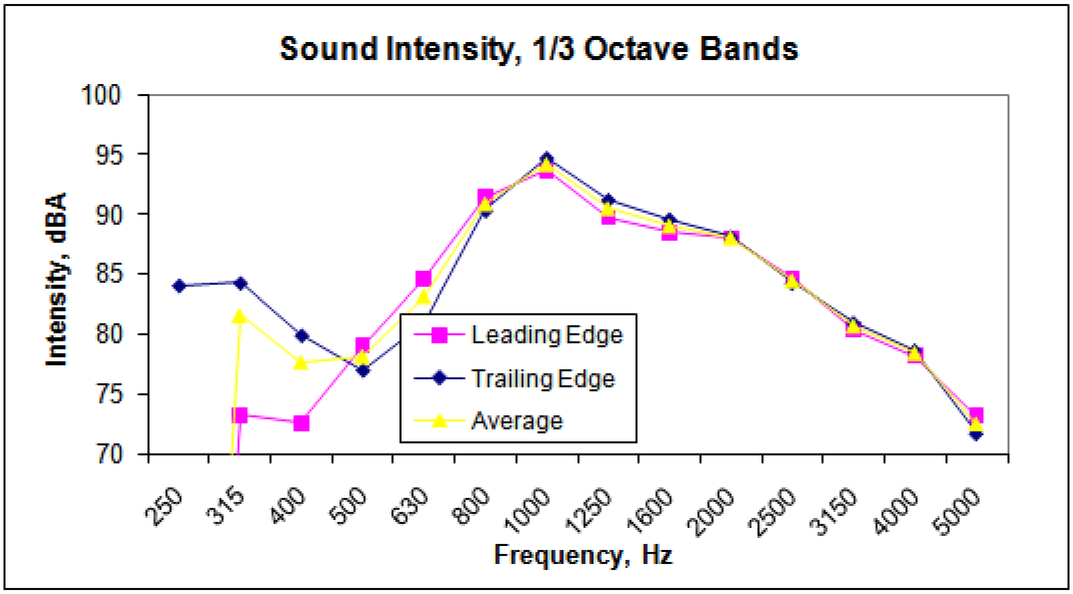


Figure D.18. MnROAD Cell 9 Passing Lane Trial 2

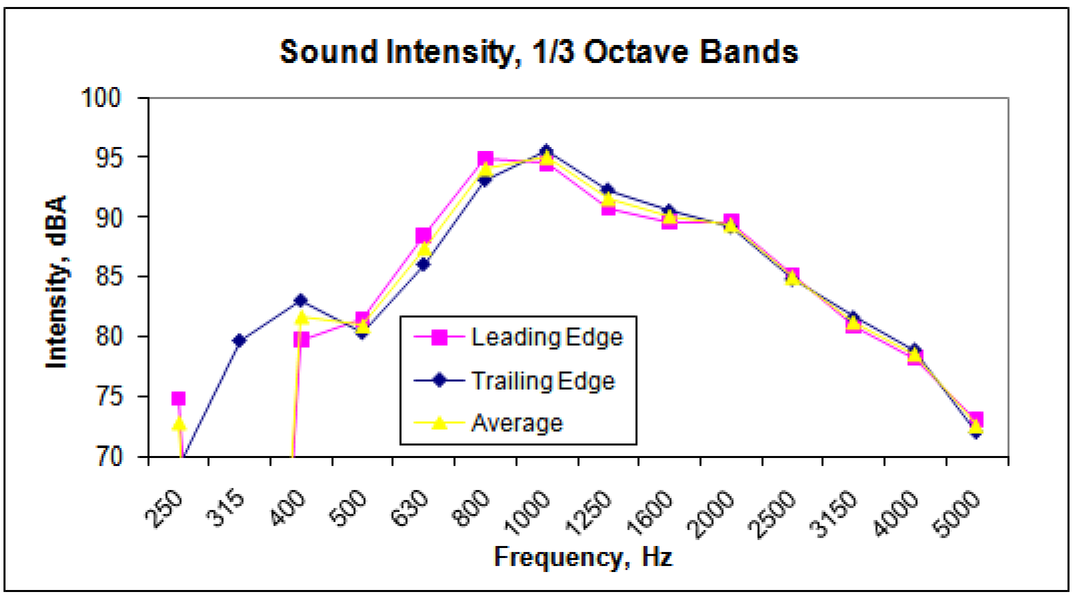


Figure D.19. MnROAD Cell 9 Passing Lane Trial 3

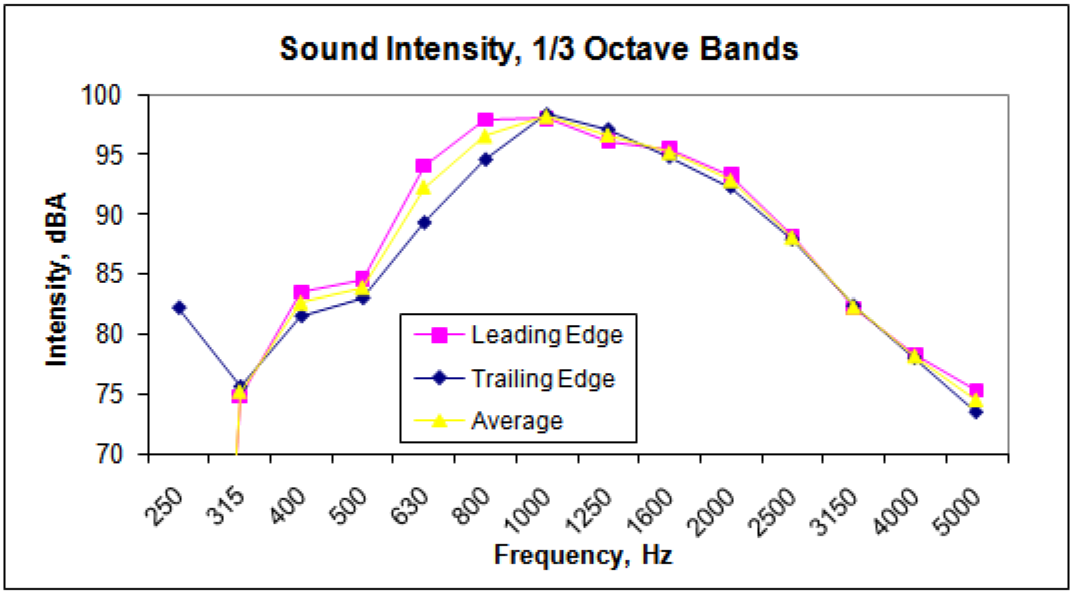


Figure D.20. MnROAD Cell 12 Driving Lane Trial 1

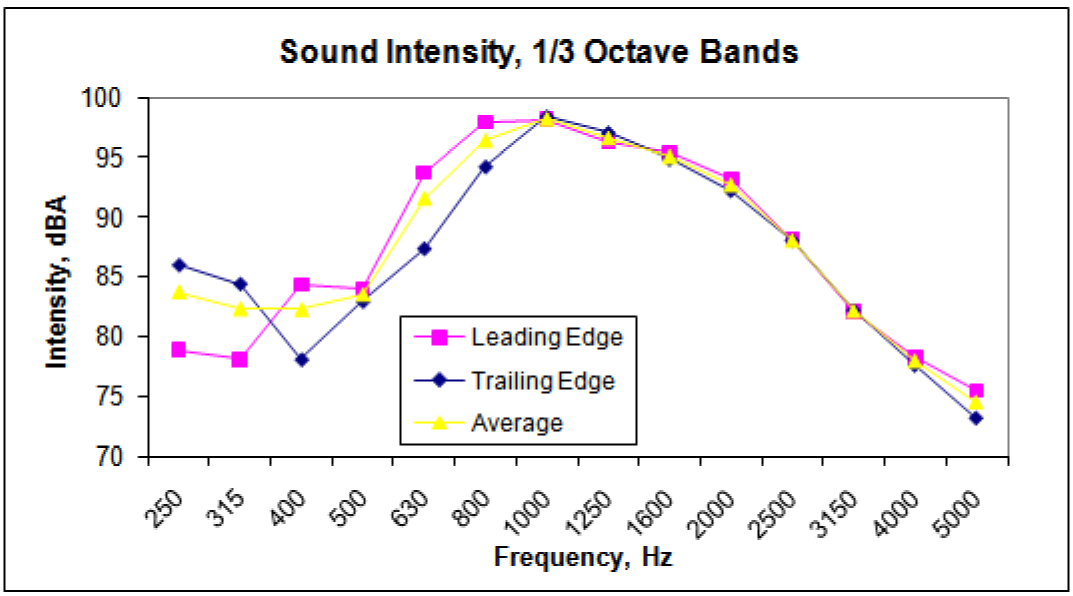


Figure D.21. MnROAD Cell 12 Driving Lane Trial 2

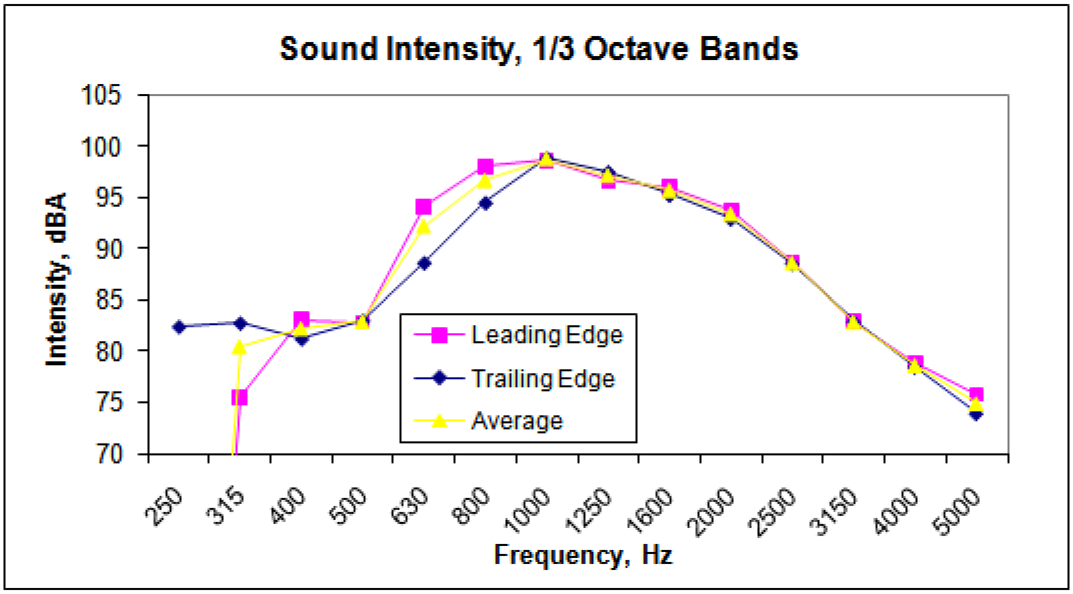


Figure D.22. MnROAD Cell 12 Driving Lane Trial 3

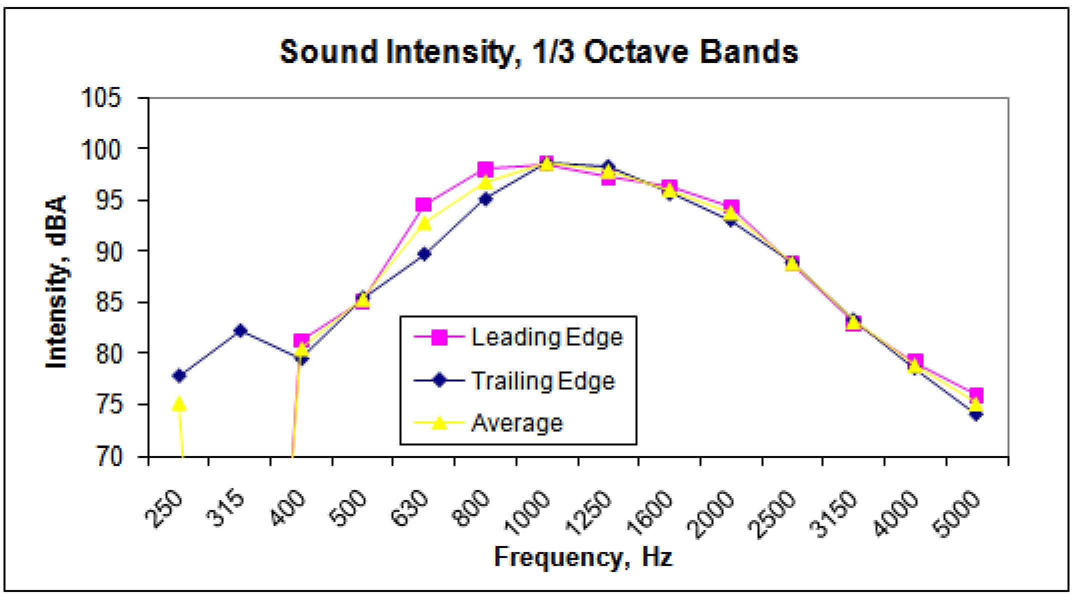


Figure D.23. MnROAD Cell 12 Passing Lane Trial 1

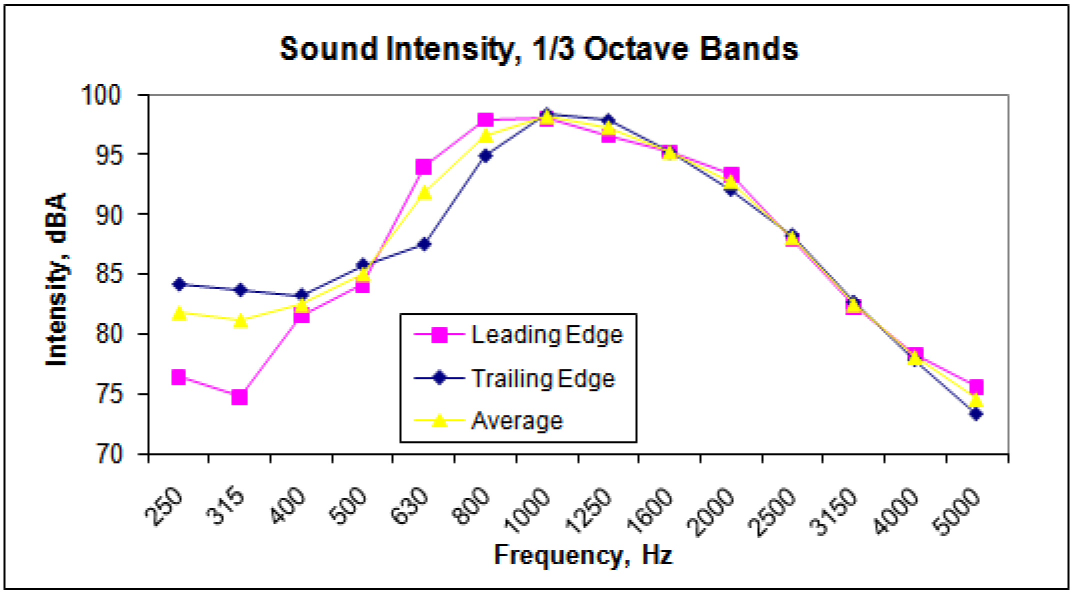


Figure D.24. MnROAD Cell 12 Passing Lane Trial 2

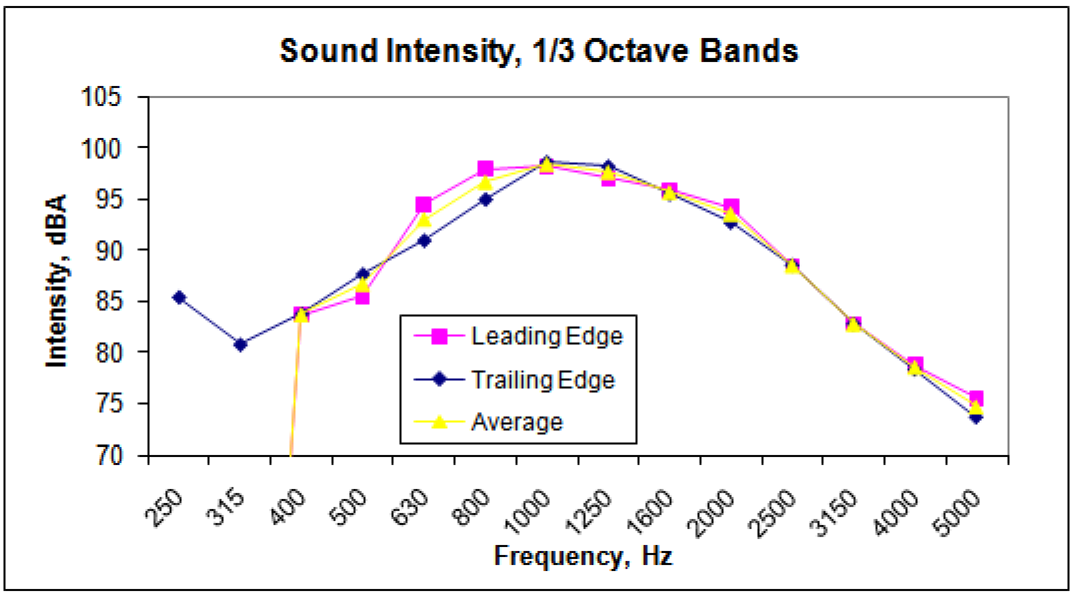


Figure D.25. MnROAD Cell 12 Passing Lane Trial 3

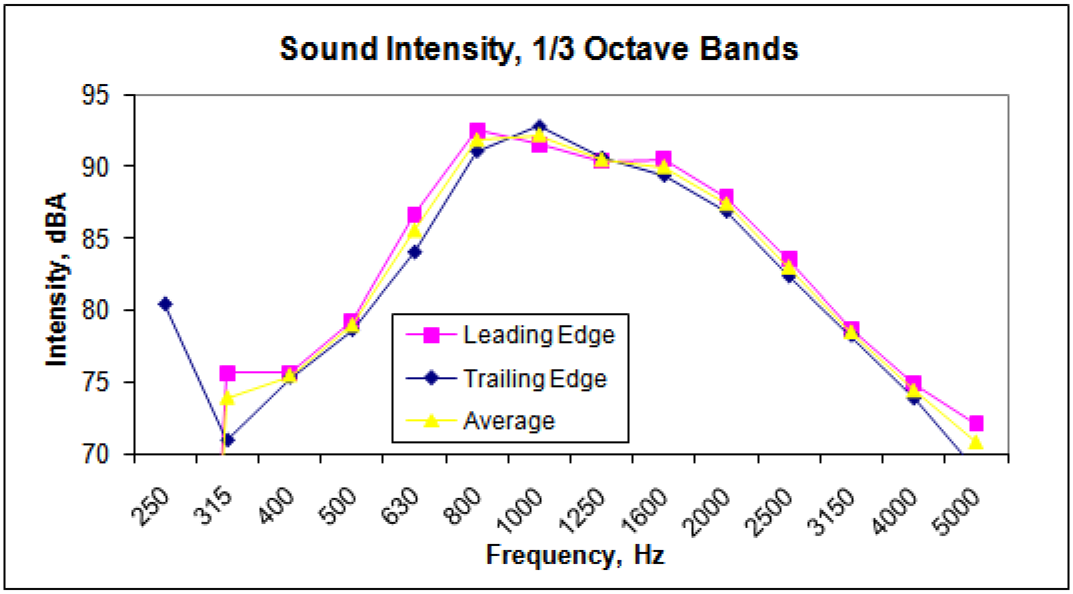


Figure D.26. MnROAD Cell 4 Driving Lane Trial 1

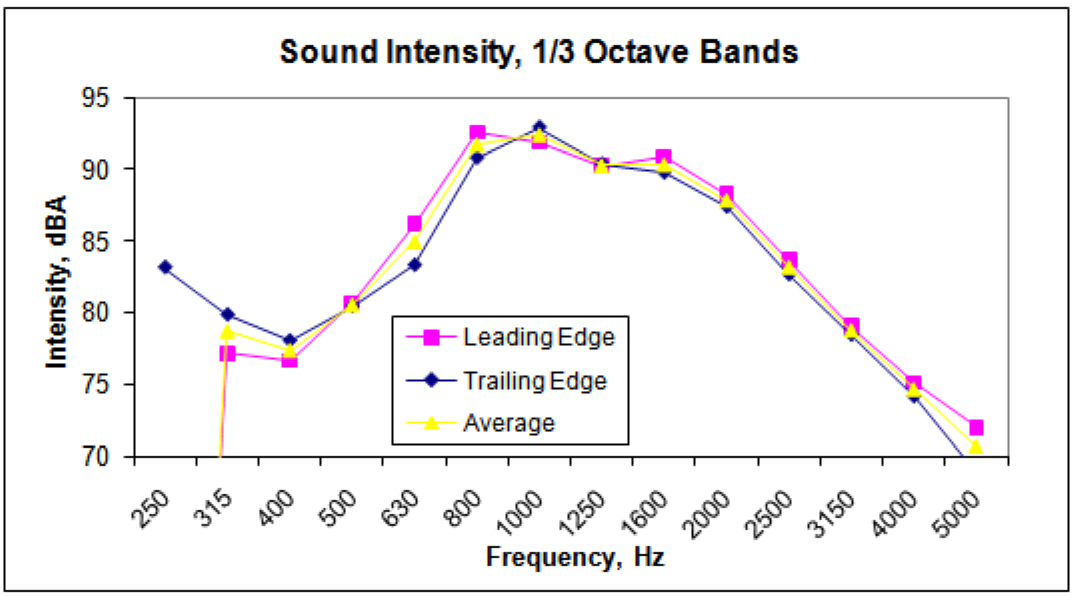


Figure D.27. MnROAD Cell 4 Driving Lane Trial 2

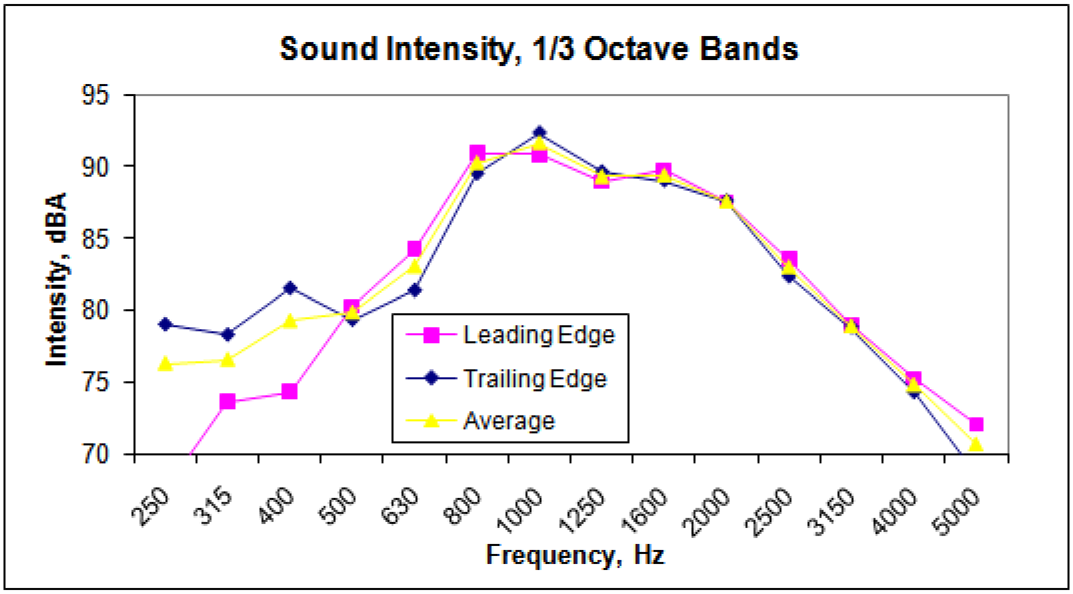


Figure D.28. MnROAD Cell 4 Driving Lane Trial 3

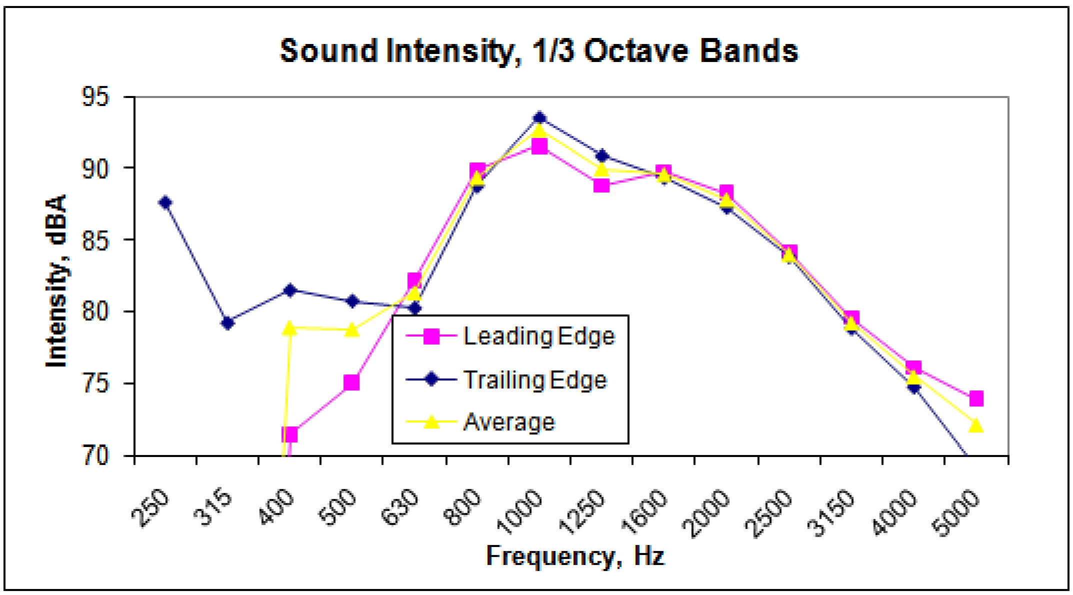


Figure D.29. MnROAD Cell 4 Passing Lane Trial 1

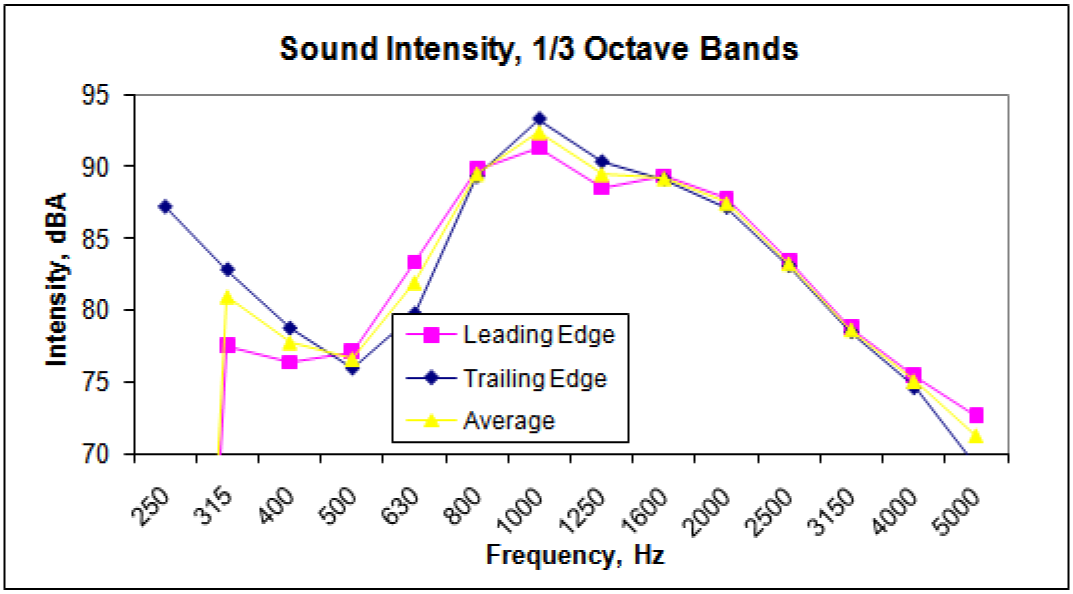


Figure D.30. MnROAD Cell 4 Passing Lane Trial 2

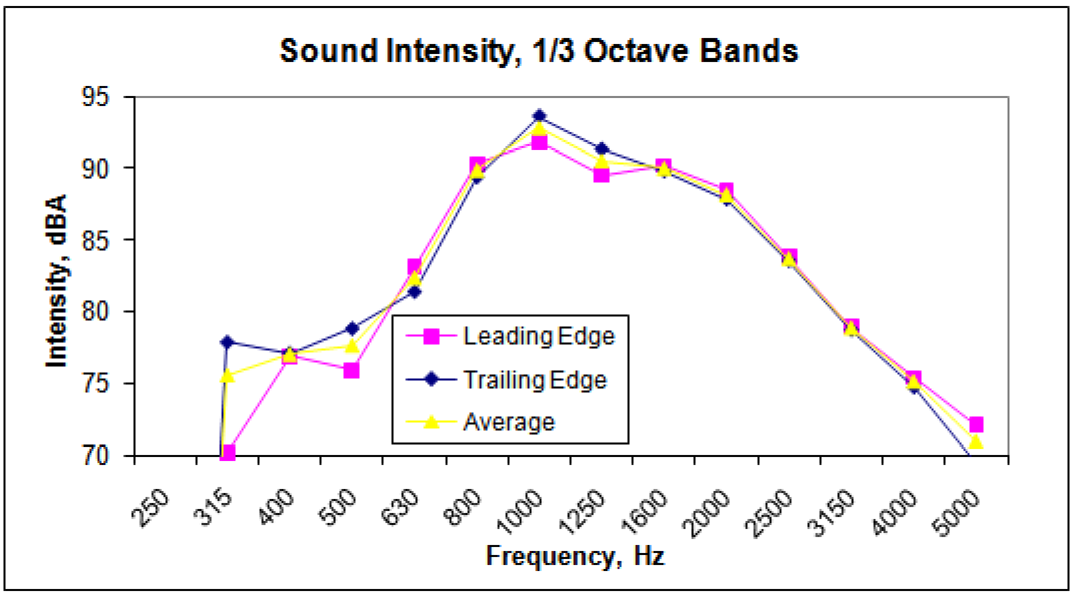


Figure D.31. MnROAD Cell 4 Passing Lane Trail 3

ST CLOUD TEST SECTION PARALLEL OBSI RESULTS

Table D.14. OBSI SUMMARY FOR ST CLOUD TEST SECTION

Average OBSI			
Direction and Lane	Innovative Grind	Conventional Grind	Difference
WB - Driving	98.0	104.5	6.5
WB +500 - Driving	98.3	104.3	6.0
WB - Passing	98.0	104.3	6.3
WB +500 - Passing	98.2	103.9	5.7
Average OBSI			
Direction	Innovative Grind	Original Texture	Difference
EB - Driving	98.9	103.3	4.4
EB +500 - Driving	98.8	103.3	4.5
EB - Passing	98.7	103.3	4.6
EB +500 - Passing	98.5	103.3	4.8
WB - Driving	98.0	103.3	5.3
WB +500 - Driving	98.3	103.3	5.0
WB - Passing	98.0	103.3	5.3
WB +500 - Passing	98.2	103.3	5.1

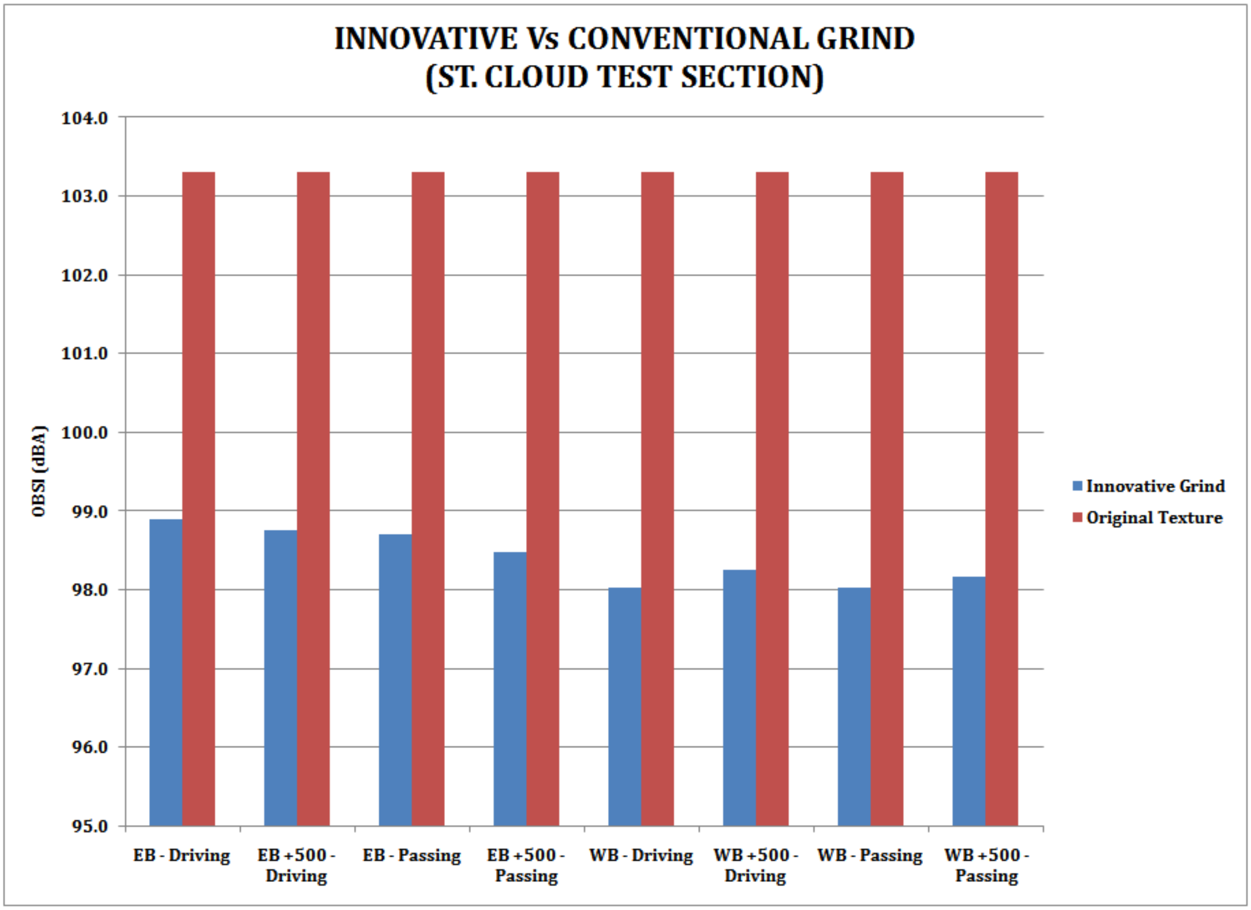


Figure D.32. Innovative grind Versus Original Texture(Before & After Analysis)

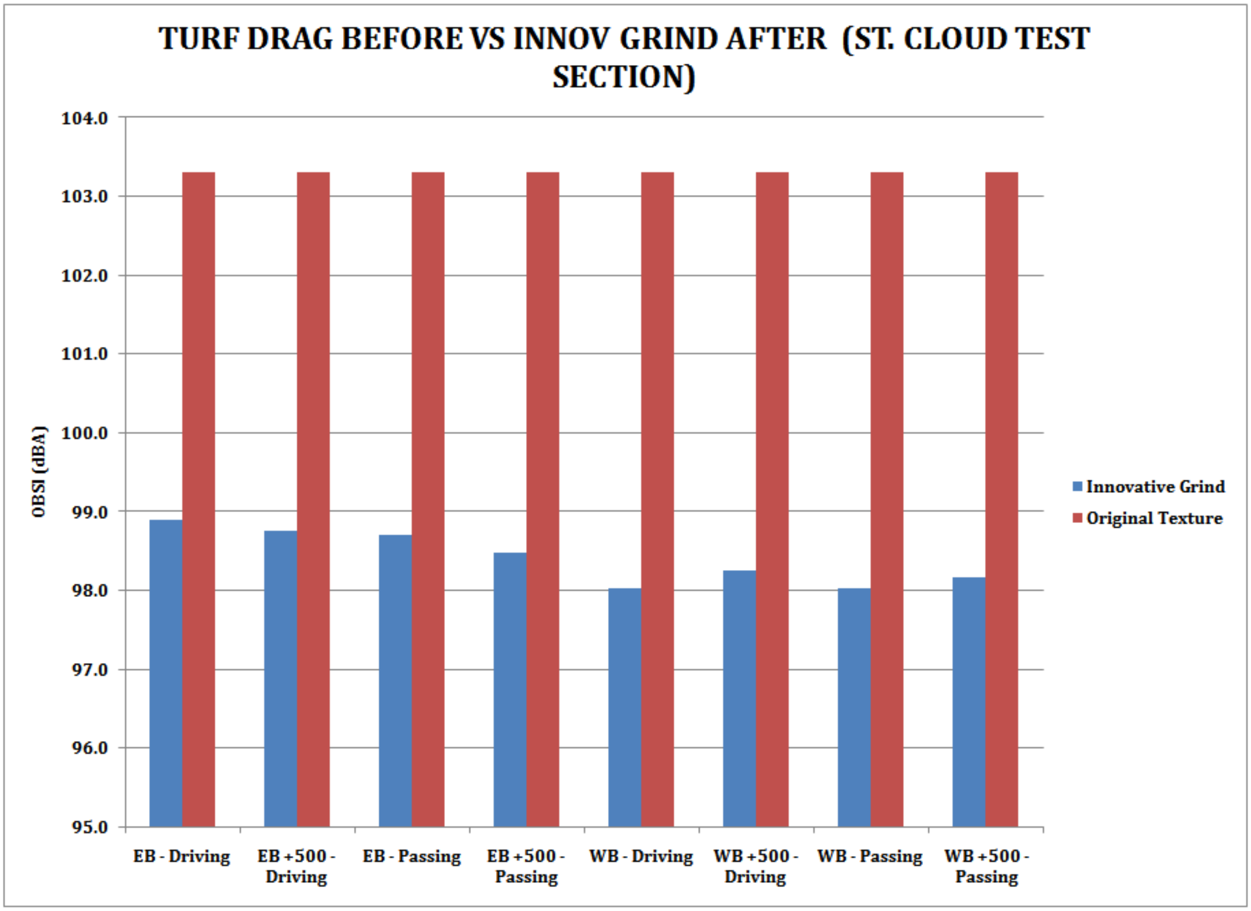


Figure D.33. Innovative grind Versus Original Texture(Before & After Analysis)

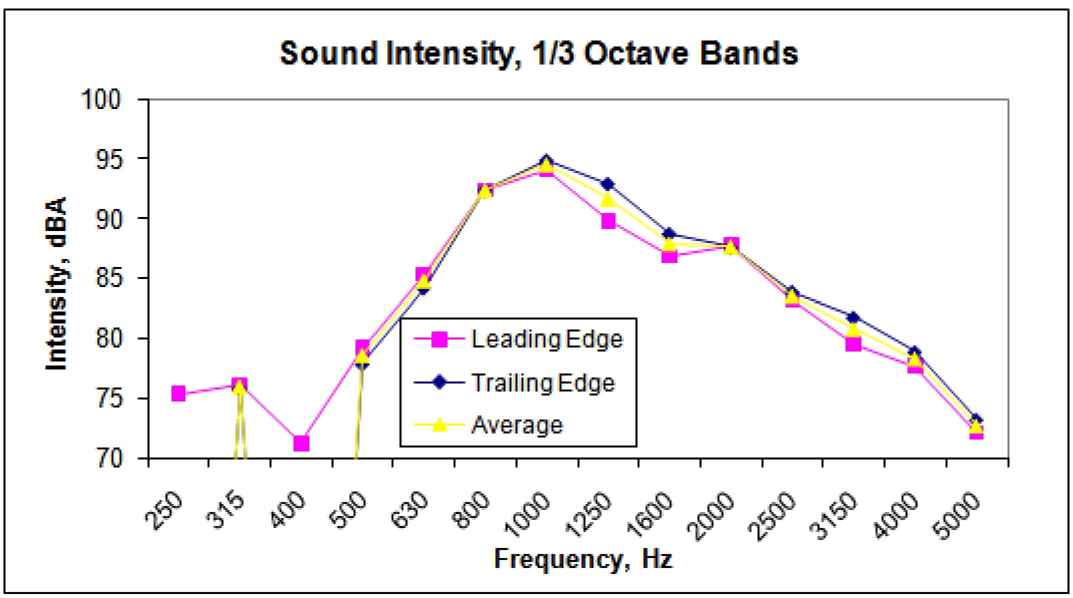


Figure D.33. St. Cloud Test Section EB Innovative Grind Driving Lane Trial 1

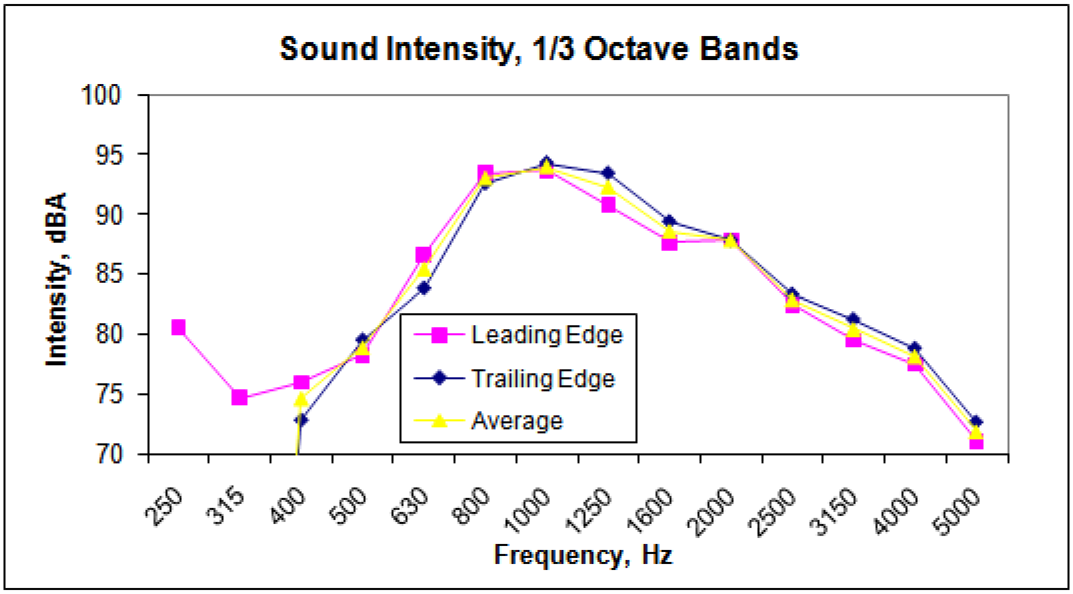


Figure D.34. St. Cloud Test Section EB Innovative Grind Driving Lane Trial 2

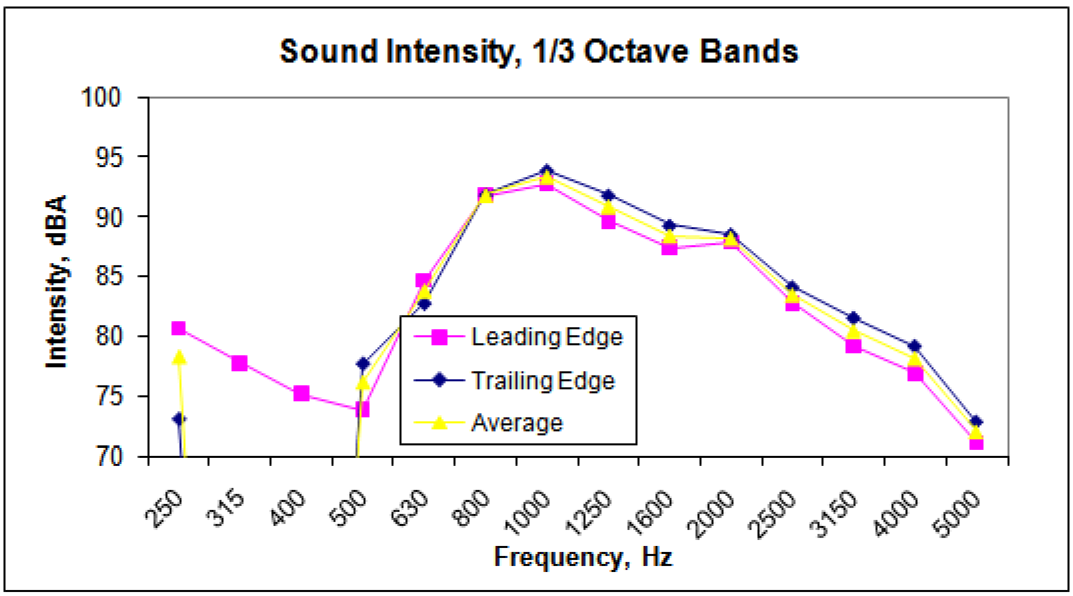


Figure D.35. St. Cloud Test Section EB Innovative Grind Driving Lane Trial 3

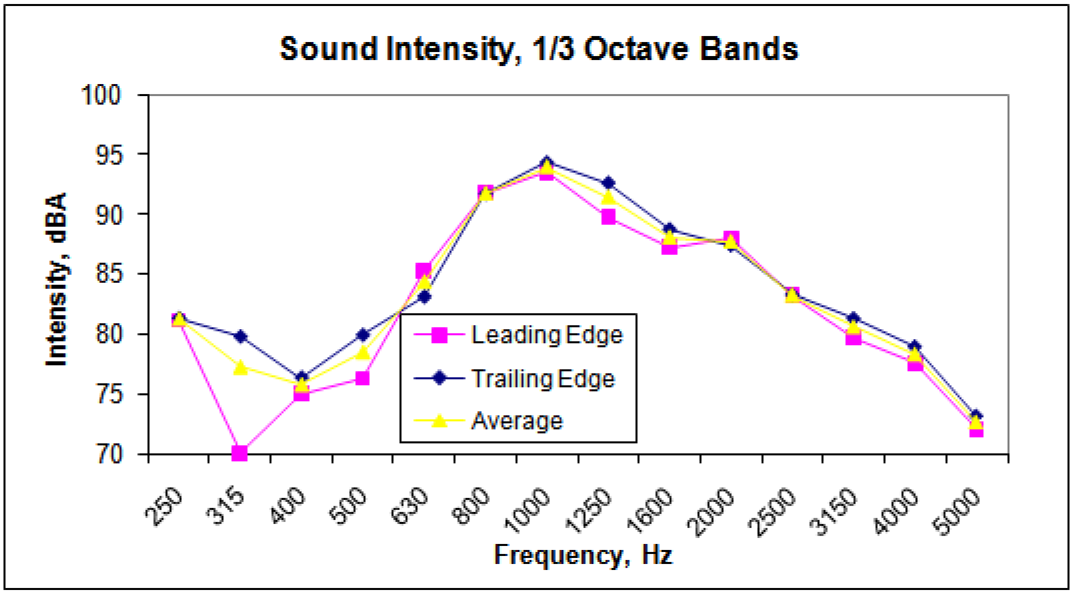


Figure D.36. St. Cloud Test Section EB +500 Innovative Grind Driving Lane Trial 1

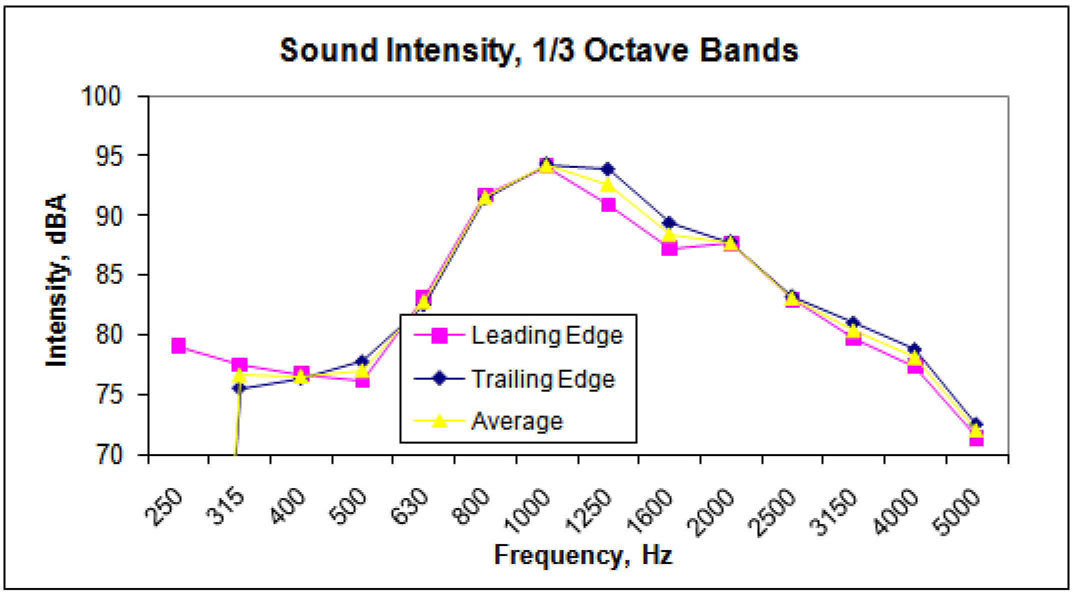


Figure D.37. St. Cloud Test Section EB +500 Innovative Grind Driving Lane Trial 2

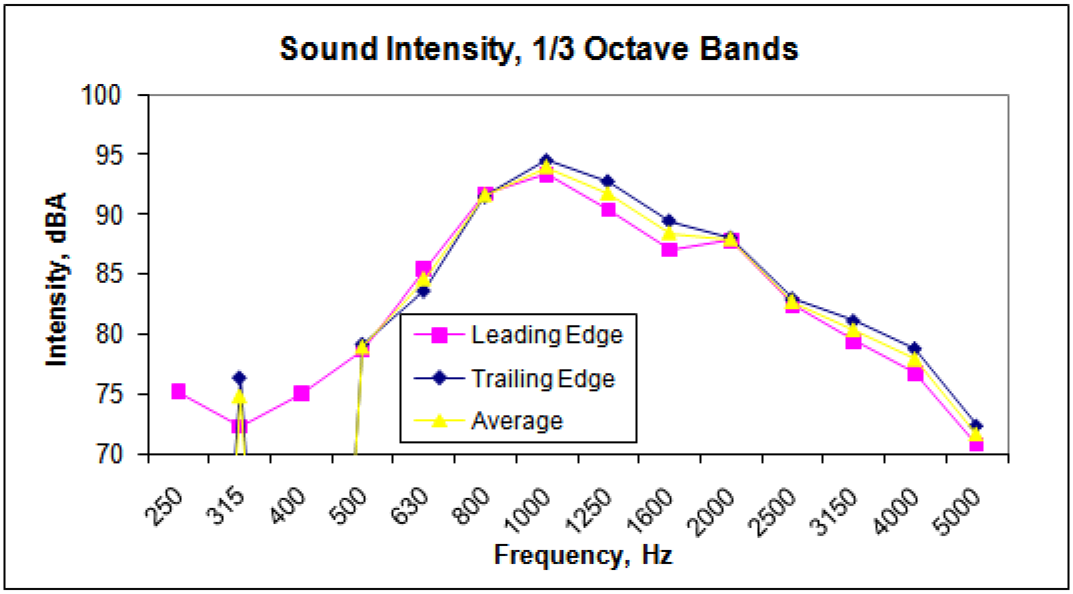


Figure D.38. St. Cloud Test Section EB +500 Innovative Grind Driving Lane Trial 3

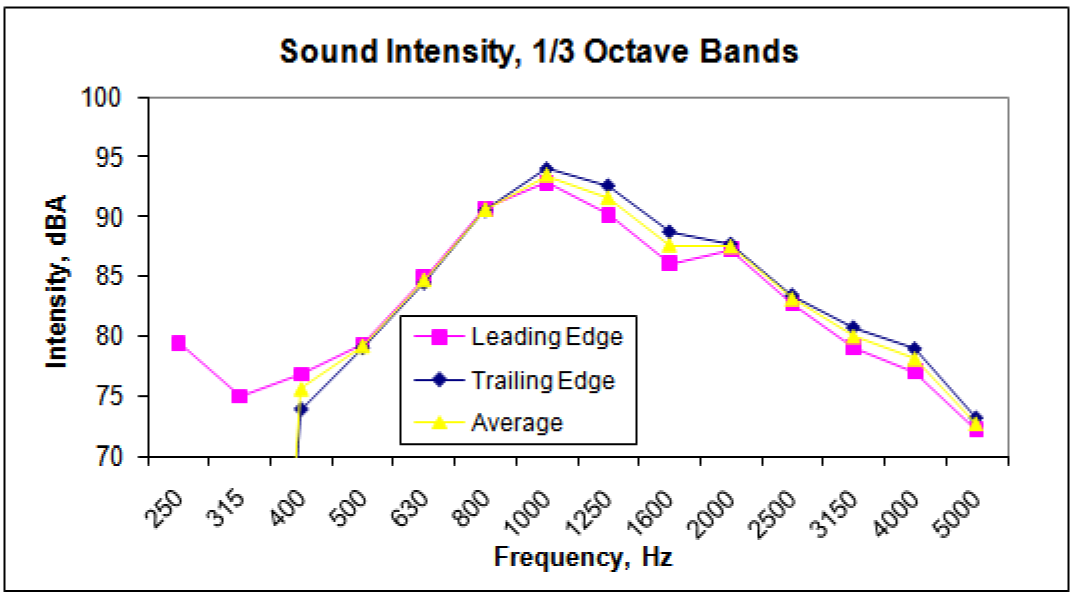


Figure D.39. St. Cloud Test Section EB Innovative Grind Passing Lane Trial 1

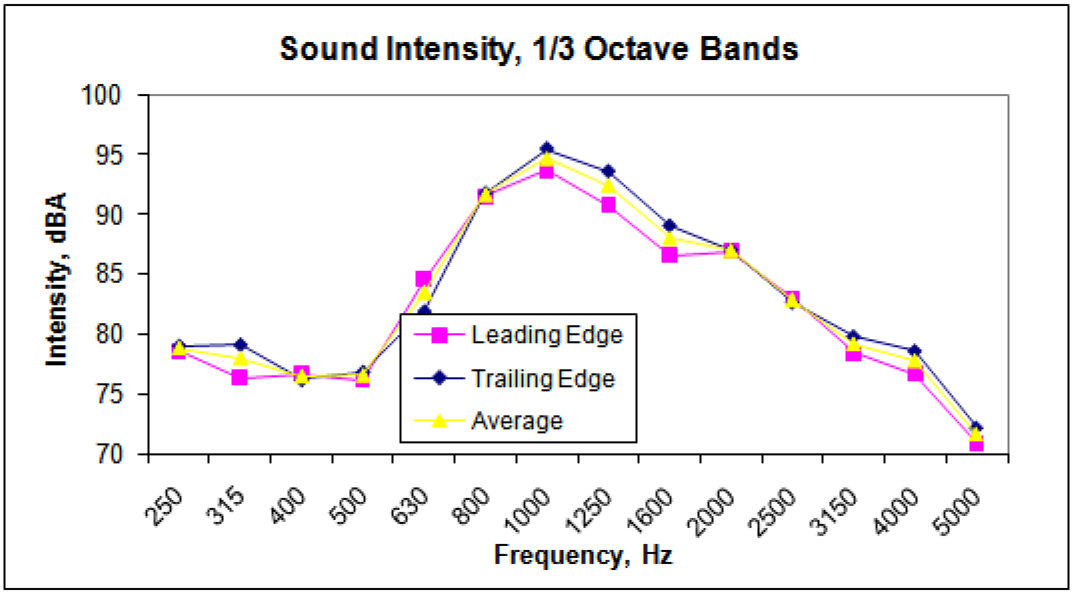


Figure D.40. St. Cloud Test Section EB Innovative Grind Passing Lane Trial 2

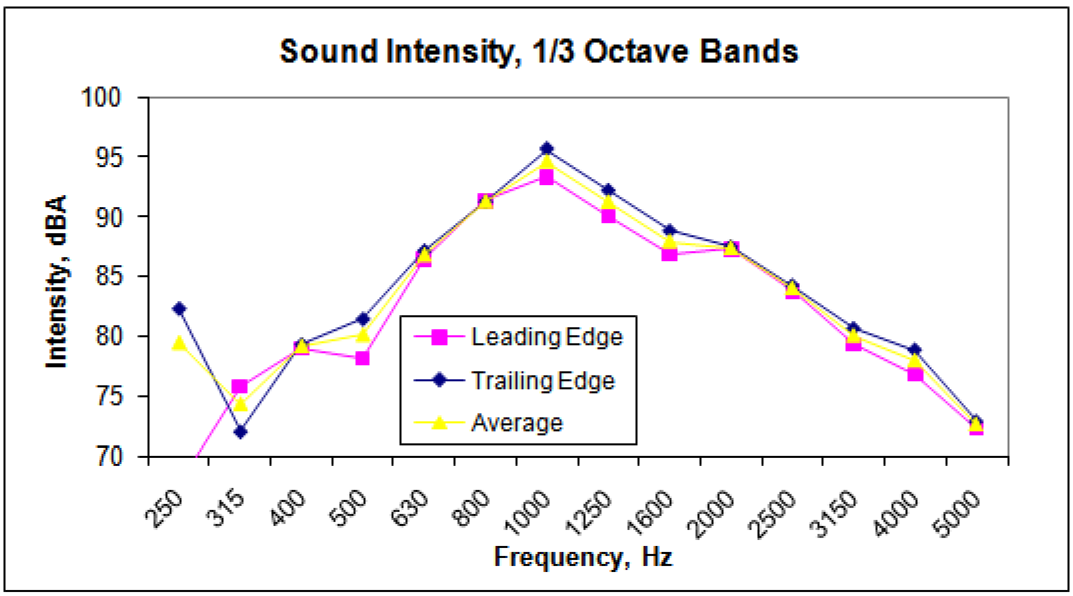


Figure D.41. St. Cloud Test Section EB Innovative Grind Passing Lane Trial 3

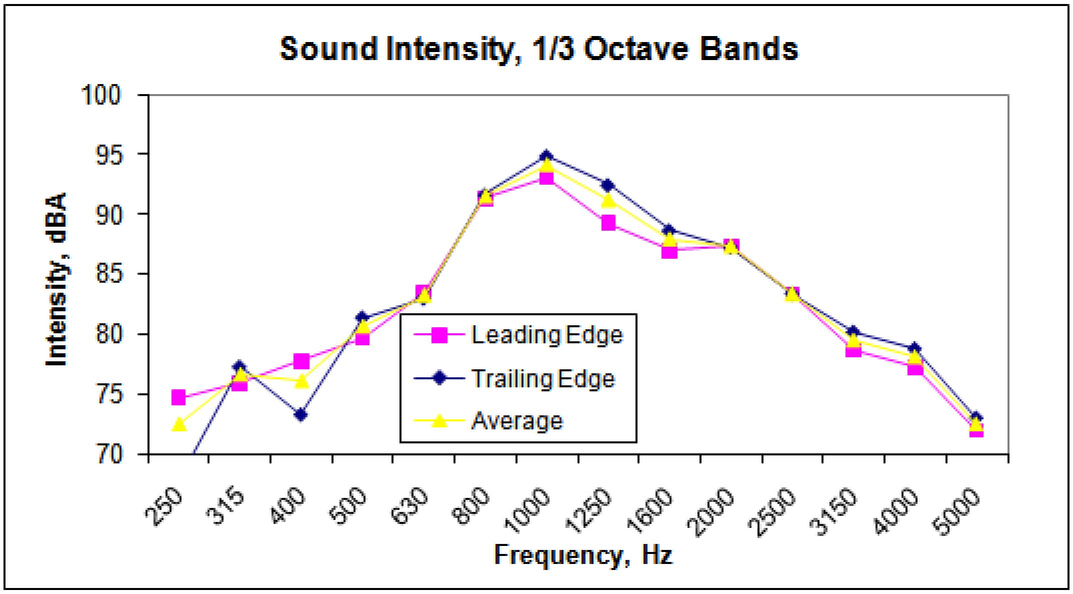


Figure D.42. St. Cloud Test Section EB +500 Innovative Grind Passing Lane Trial 1

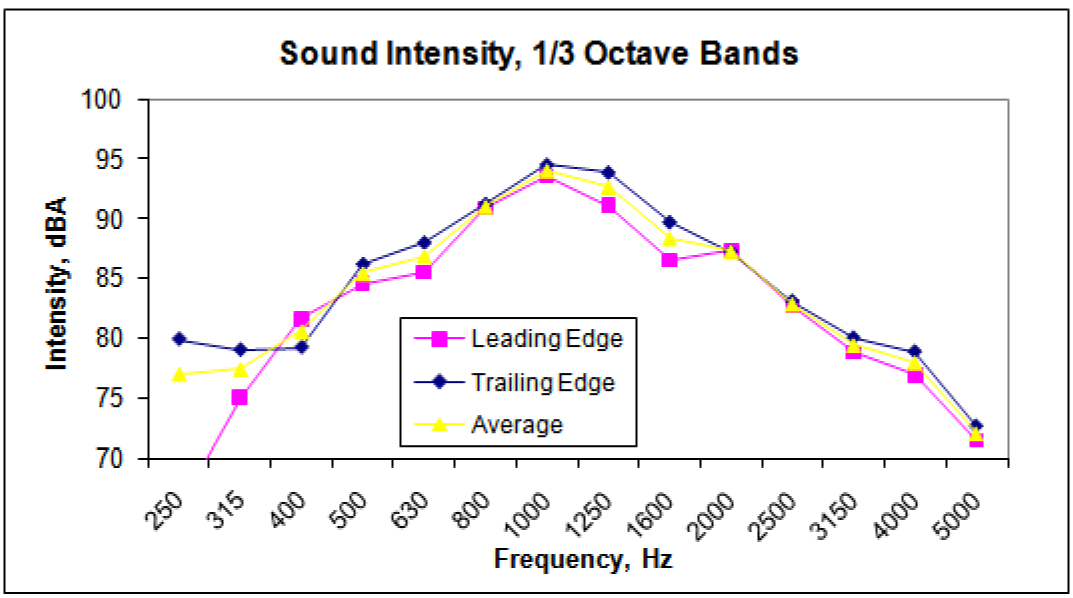


Figure D.43. St. Cloud Test Section EB +500 Innovative Grind Passing Lane Trial 2

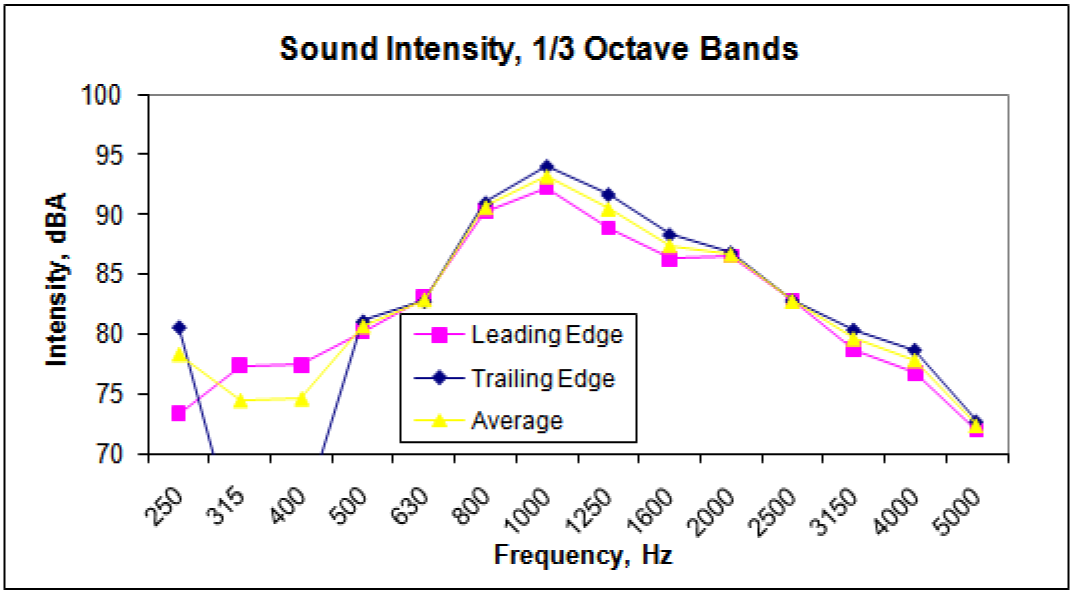


Figure D.44. St. Cloud Test Section EB +500 Innovative Grind Passing Lane Trial 3

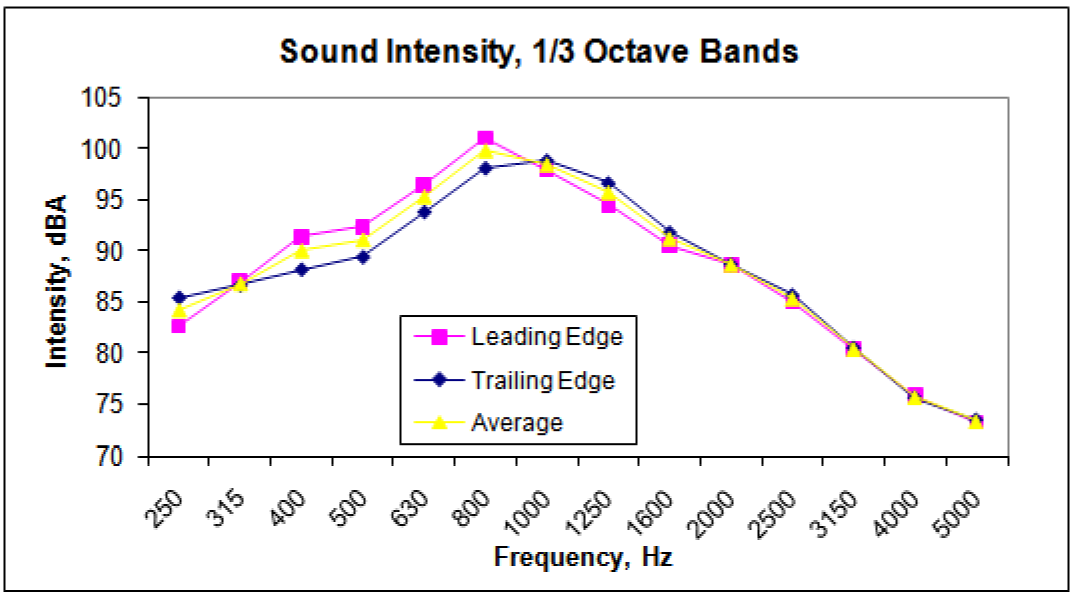


Figure D.45. St. Cloud Test Section WB Conventional Grind Driving Lane Trial 1

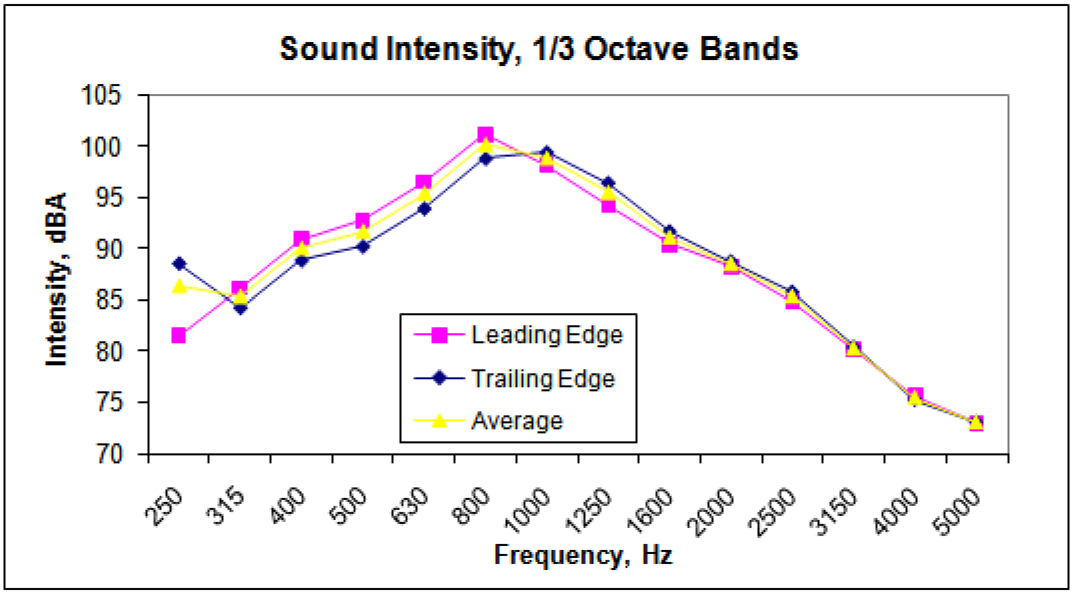


Figure D.46. St. Cloud Test Section WB Conventional Grind Driving Lane Trial 2

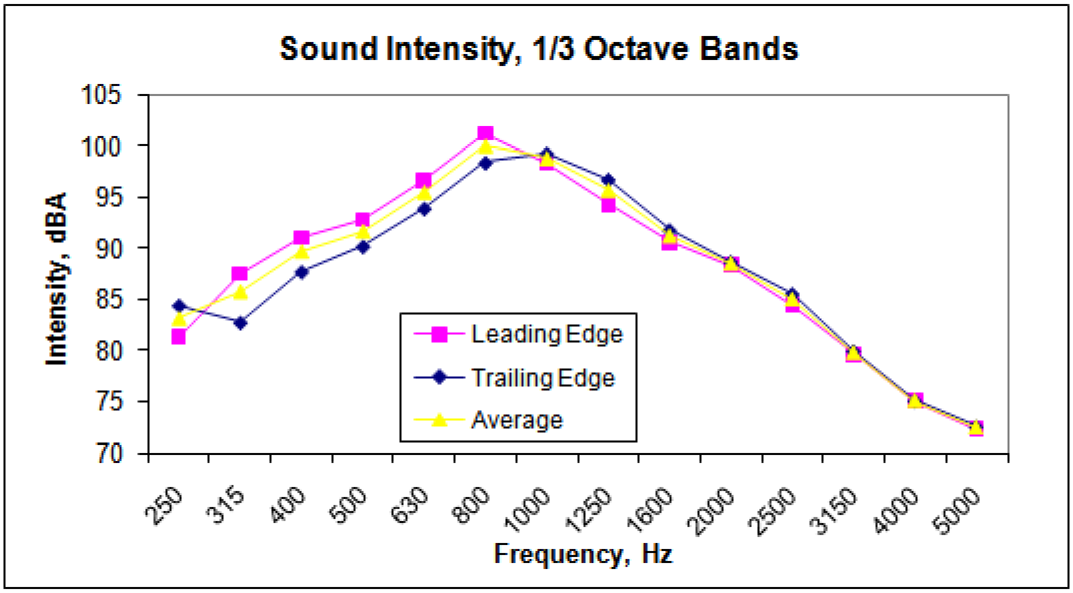


Figure D.47. St. Cloud Test Section WB Conventional Grind Driving Lane Trial 3

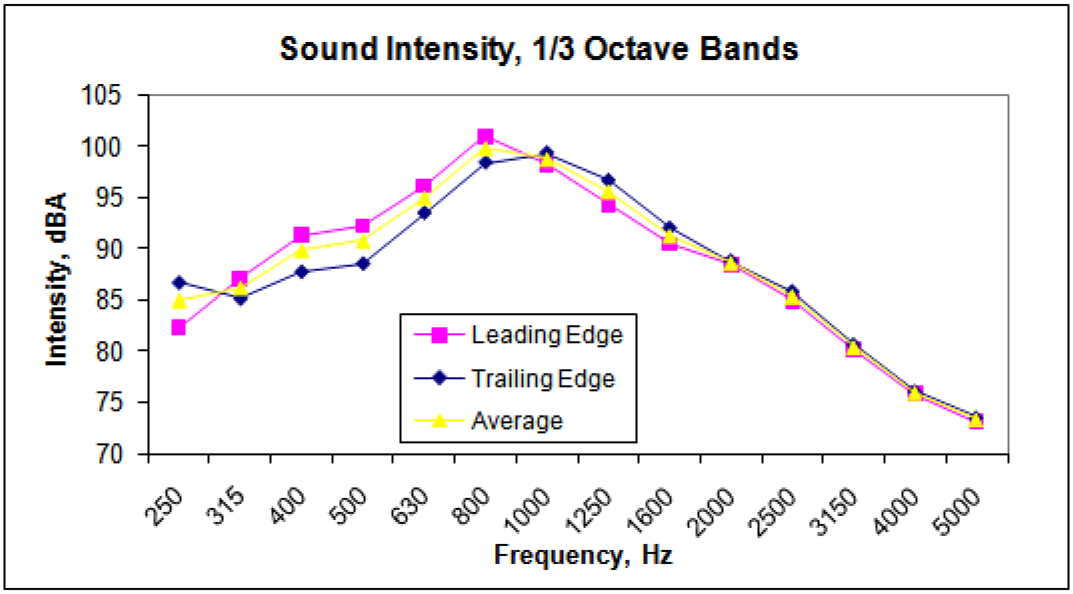


Figure D.48. St. Cloud Test Section WB +500 Conventional Grind Driving Lane Trial 1

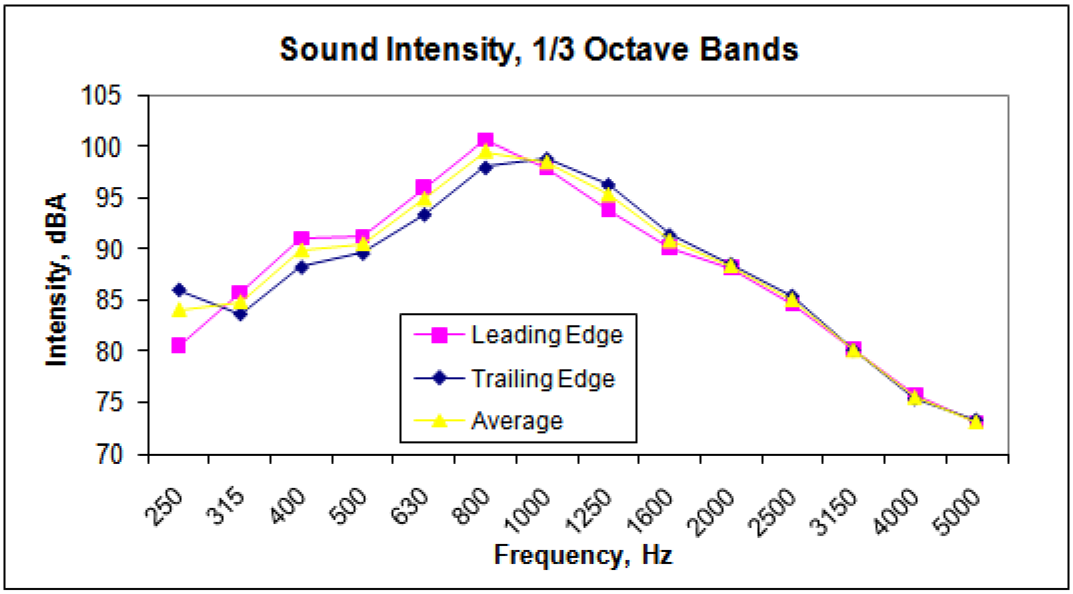


Figure D.49. St. Cloud Test Section WB +500 Conventional Grind Driving Lane Trial 2

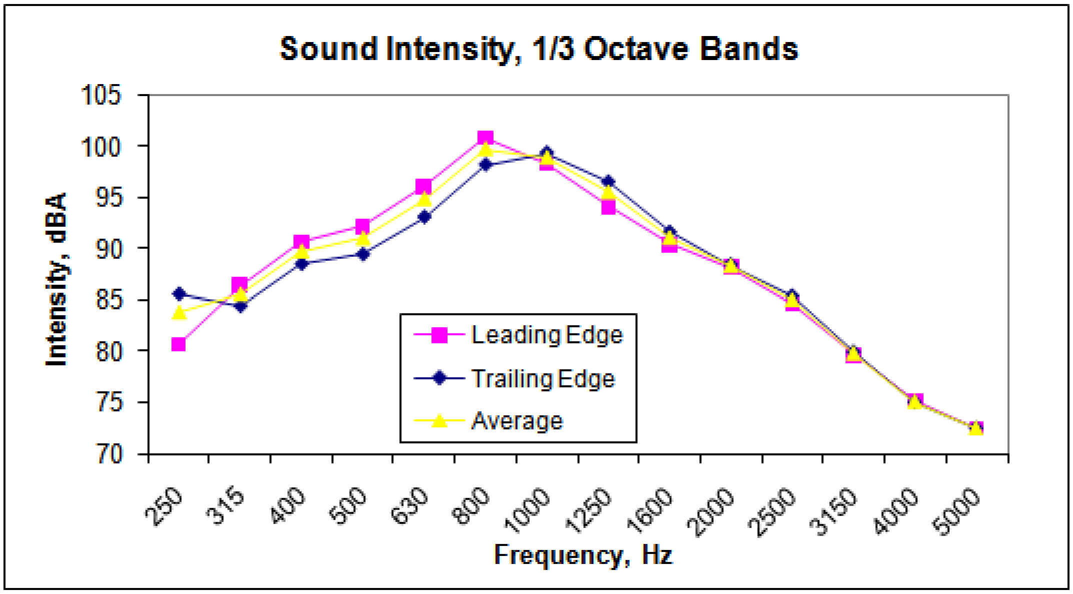


Figure D.50. St. Cloud Test Section WB +500 Conventional Grind Driving Lane Trial 3

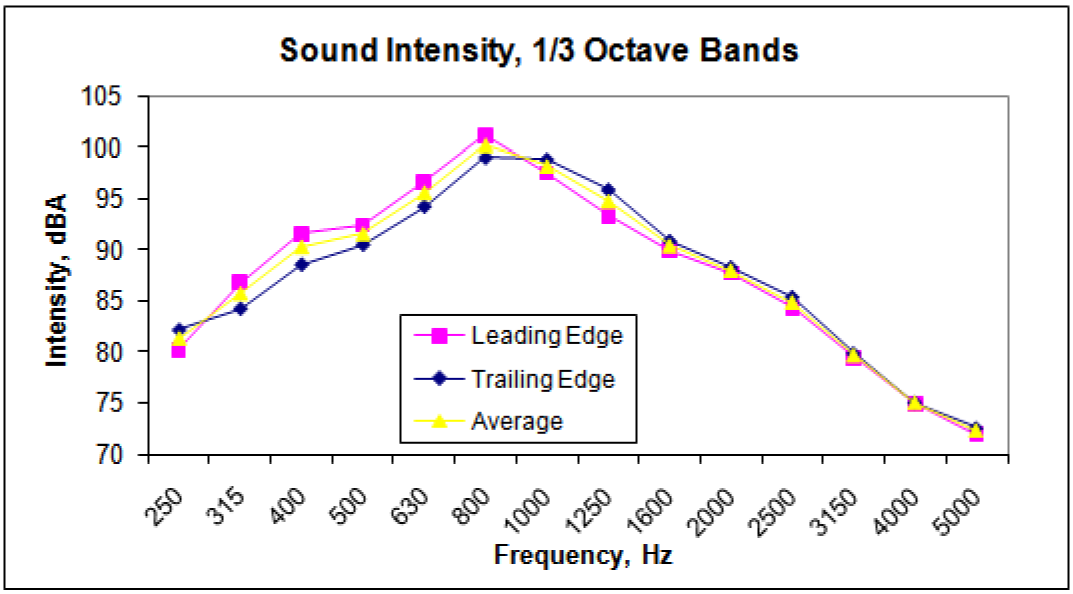


Figure D.51. St. Cloud Test Section WB Conventional Grind Passing Lane Trial 1

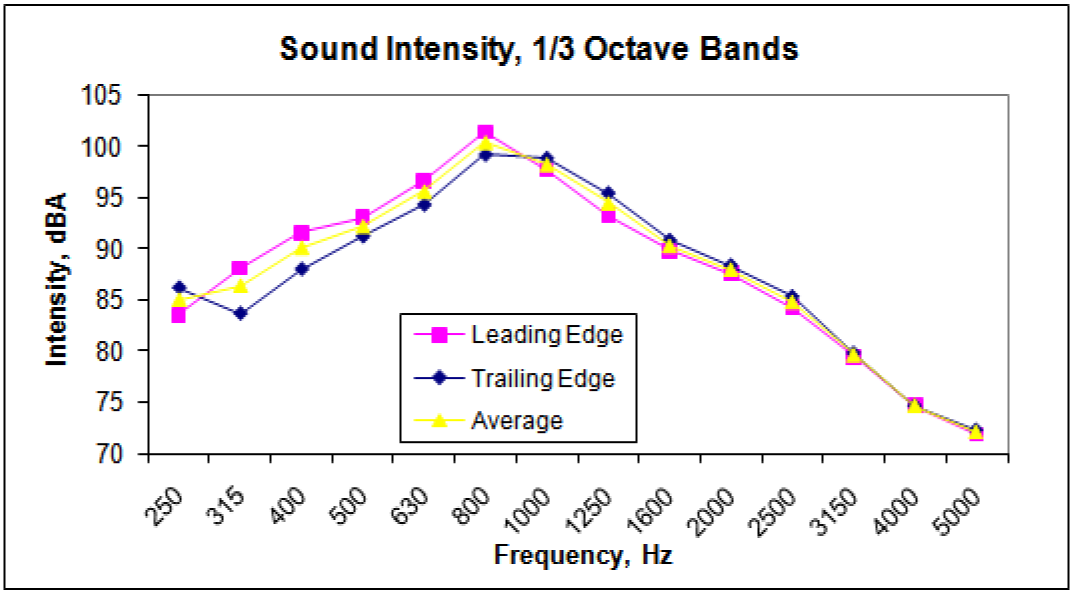


Figure D.52. St. Cloud Test Section WB Conventional Grind Passing Lane Trial 2

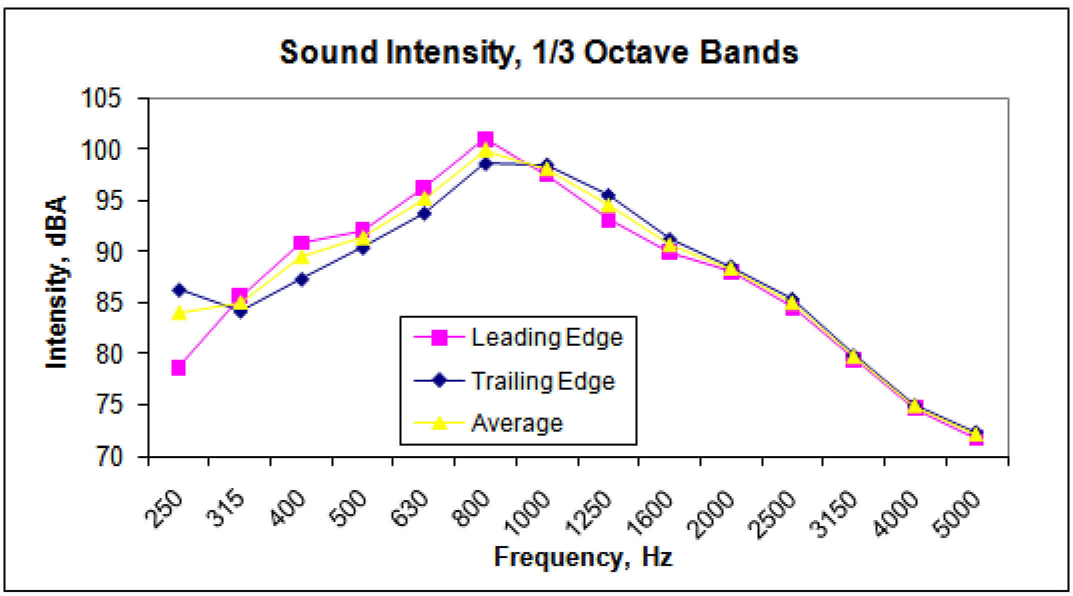


Figure D.53. St. Cloud Test Section WB Conventional Grind Passing Lane Trial 3

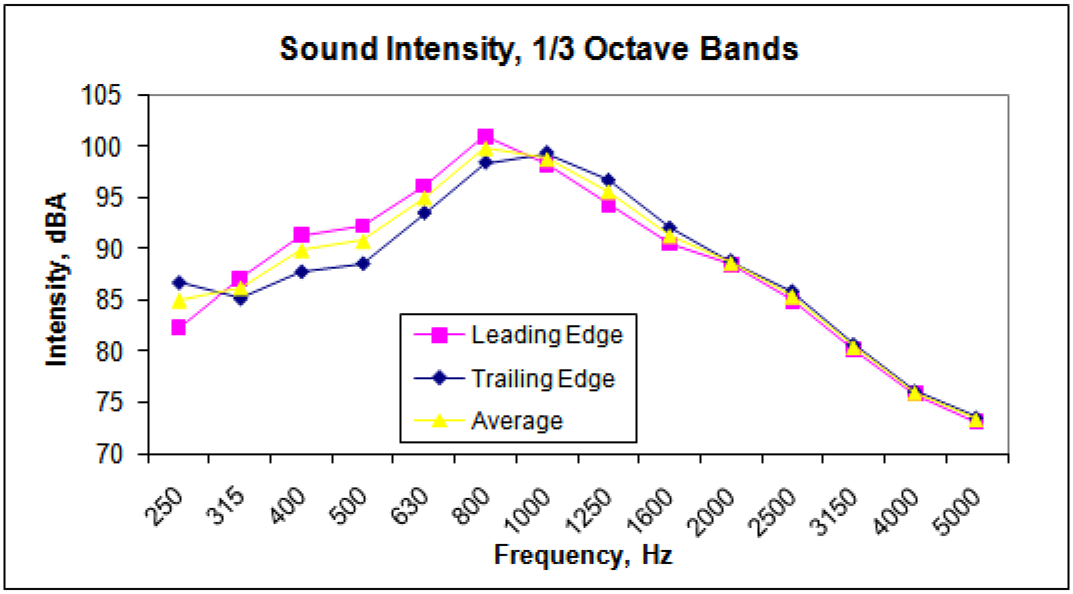


Figure D.54. St. Cloud Test Section WB +500 Conventional Grind Passing Lane Trial 1

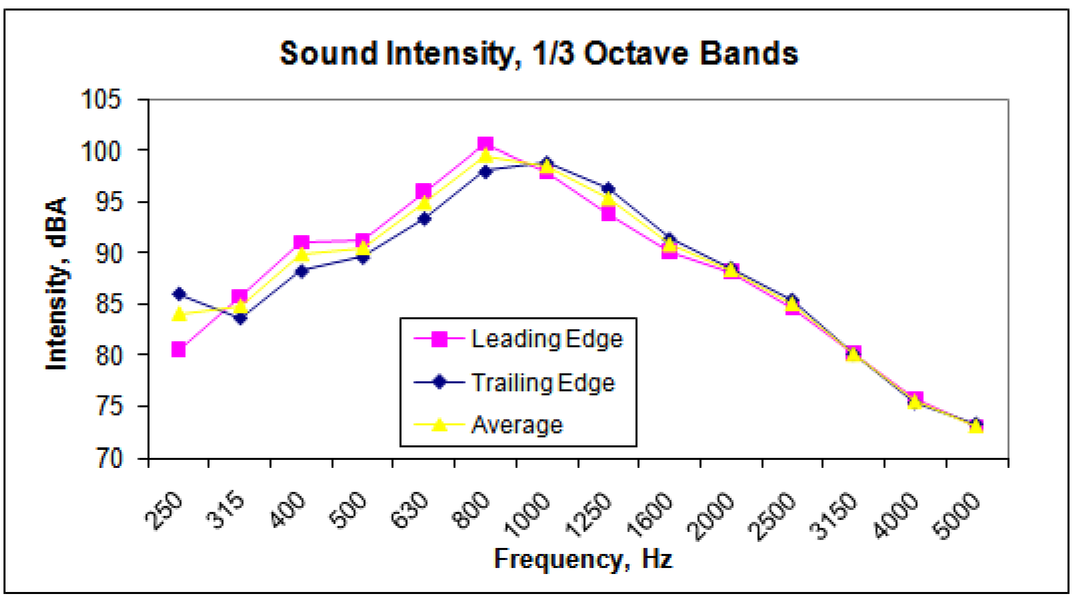


Figure D.55. St. Cloud Test Section WB +500 Conventional Grind Passing Lane Trial 2

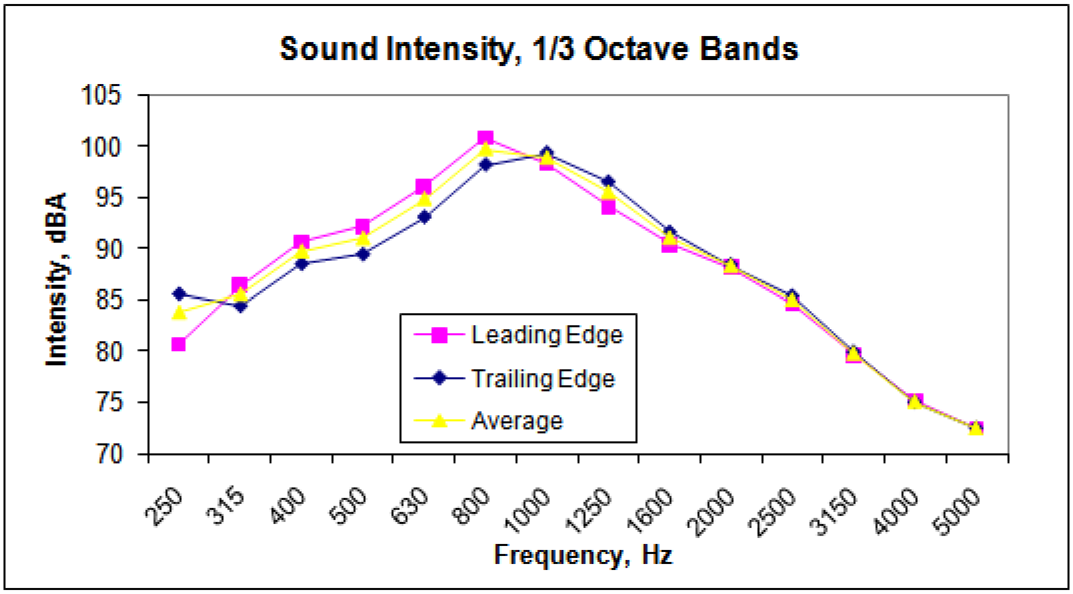


Figure D.56. St. Cloud Test Section WB +500 Conventional Grind Passing Lane Trial 3

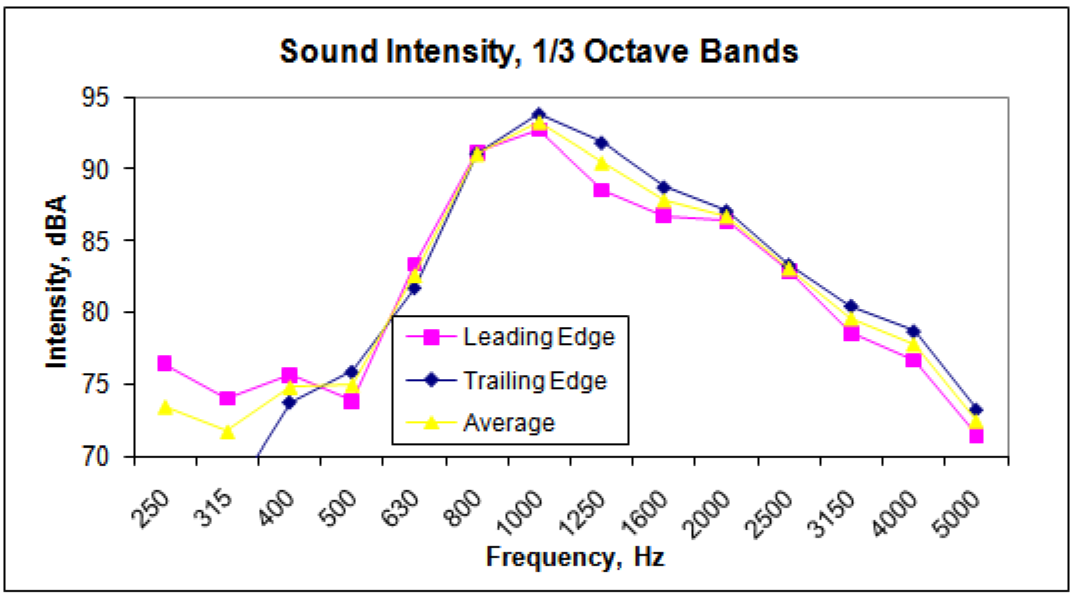


Figure D.57. St. Cloud Test Section WB Innovative Grind Driving Lane Trial 1

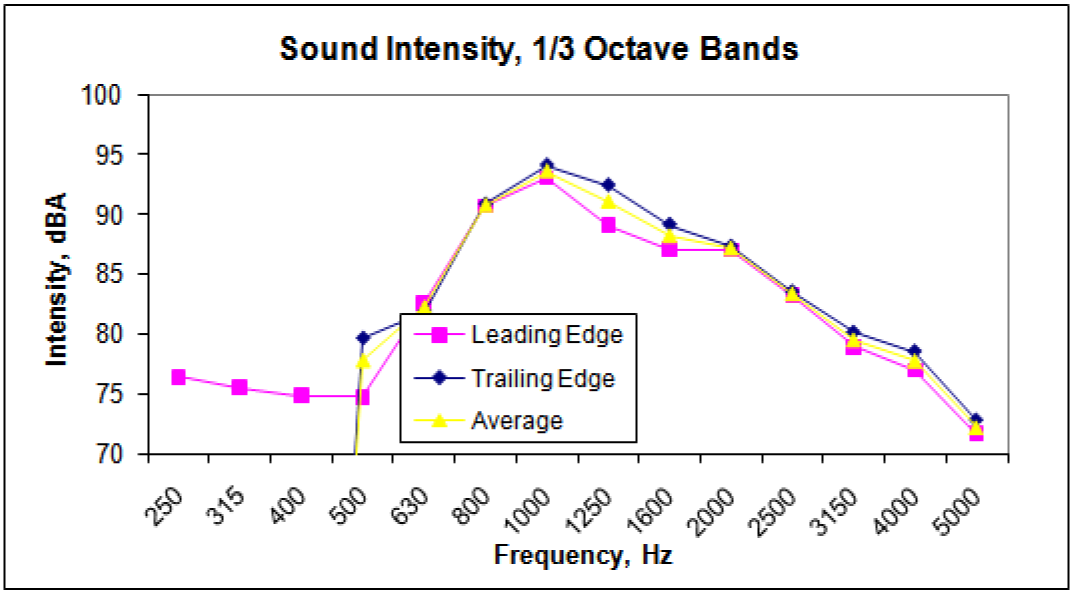


Figure D.58. St. Cloud Test Section WB Innovative Grind Driving Lane Trial 2

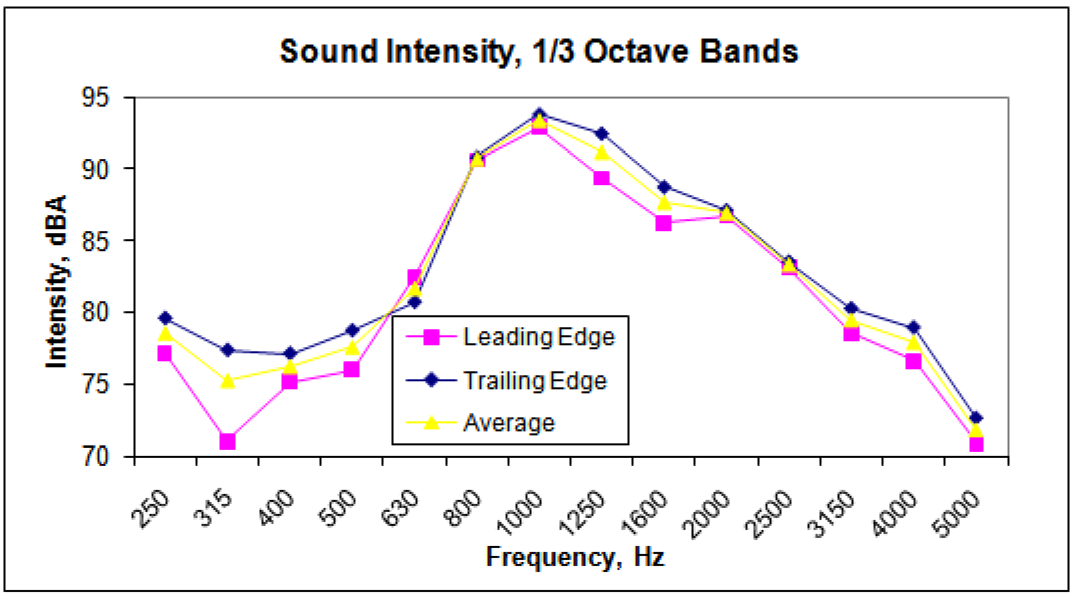


Figure D.59. St. Cloud Test Section WB Innovative Grind Driving Lane Trial 3

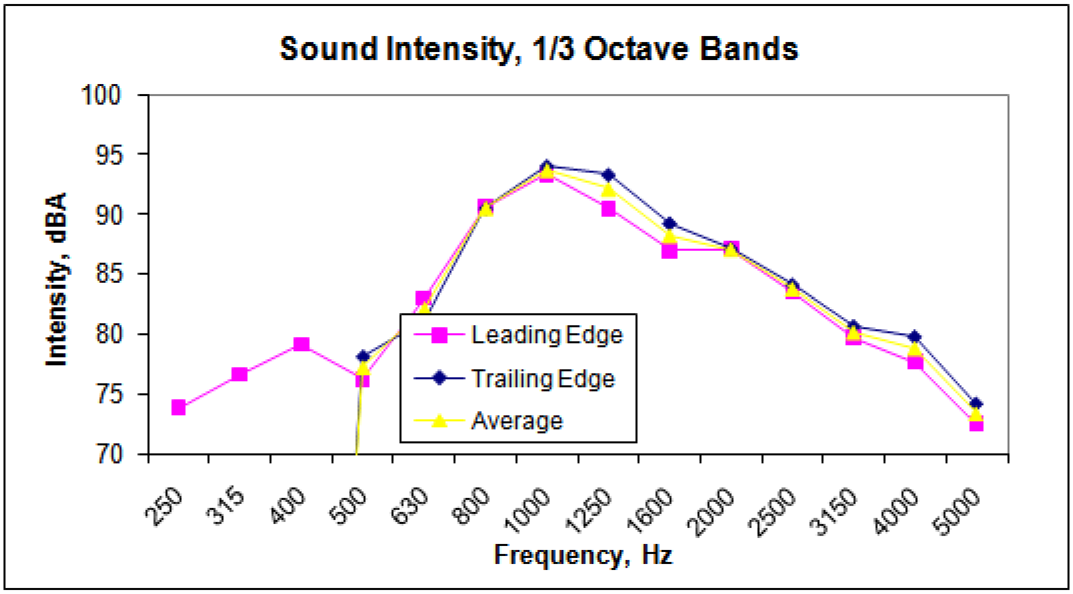


Figure D.60. St. Cloud Test Section WB +500 Innovative Grind Driving Lane Trial 1

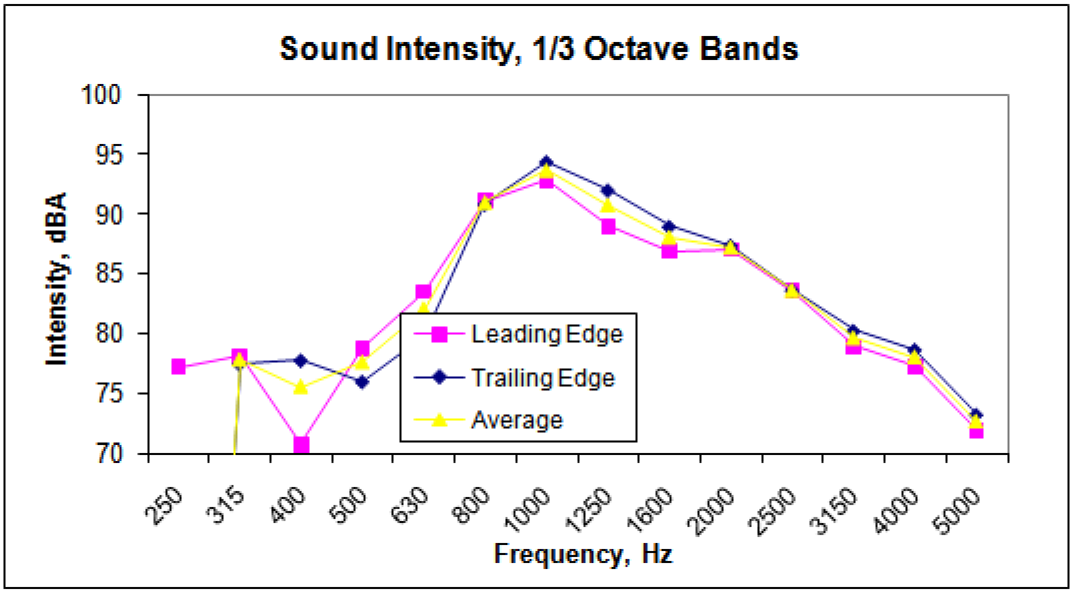


Figure D.61. St. Cloud Test Section WB +500 Innovative Grind Driving Lane Trial 2

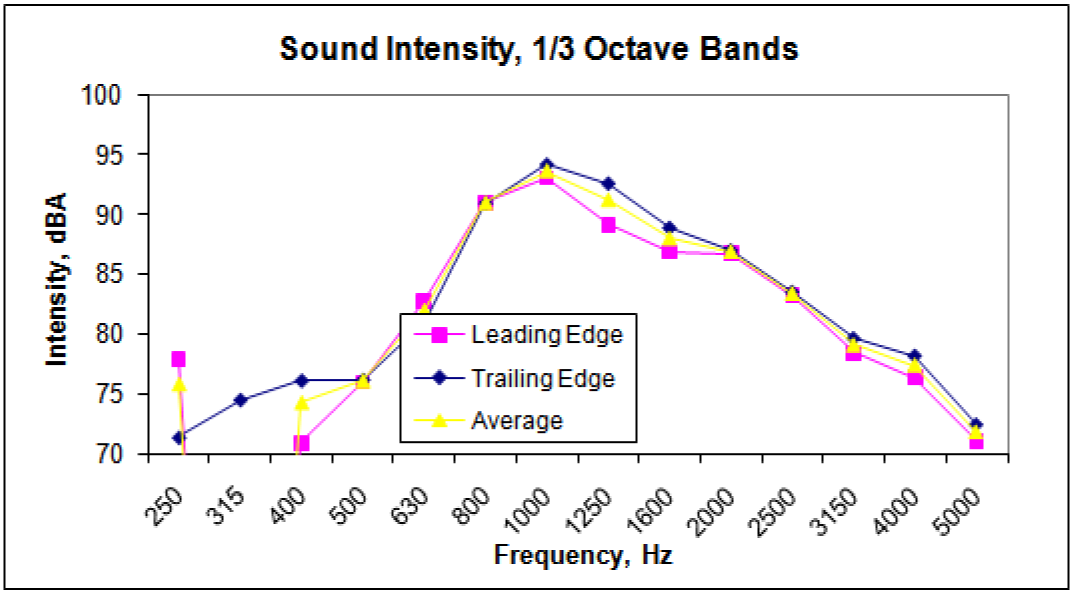


Figure D.62. St. Cloud Test Section WB +500 Innovative Grind Driving Lane Trial 3

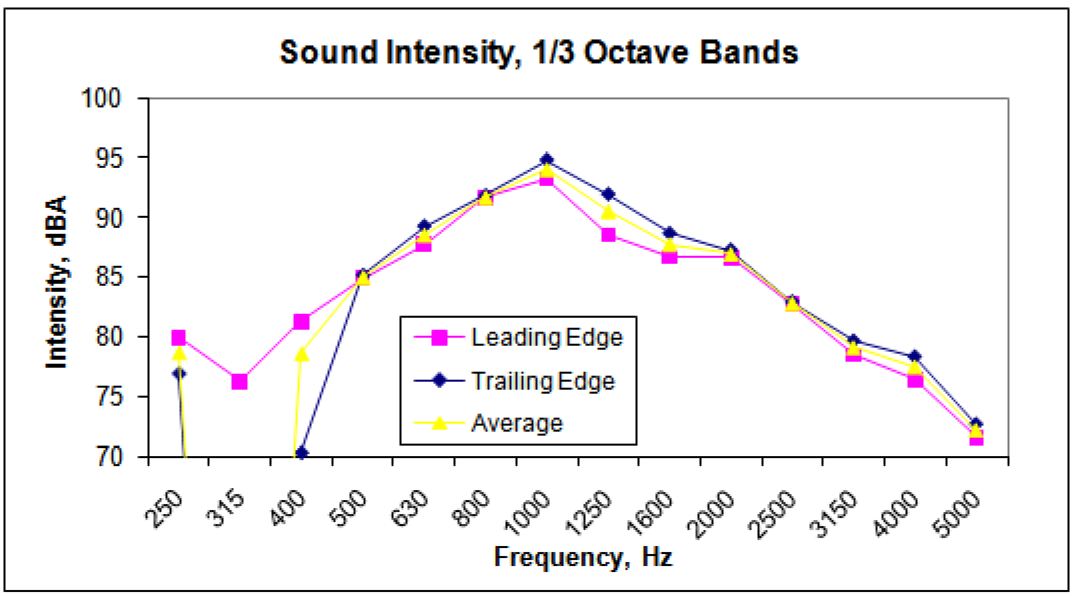


Figure D.63. St. Cloud Test Section WB Innovative Grind Passing Lane Trial 1

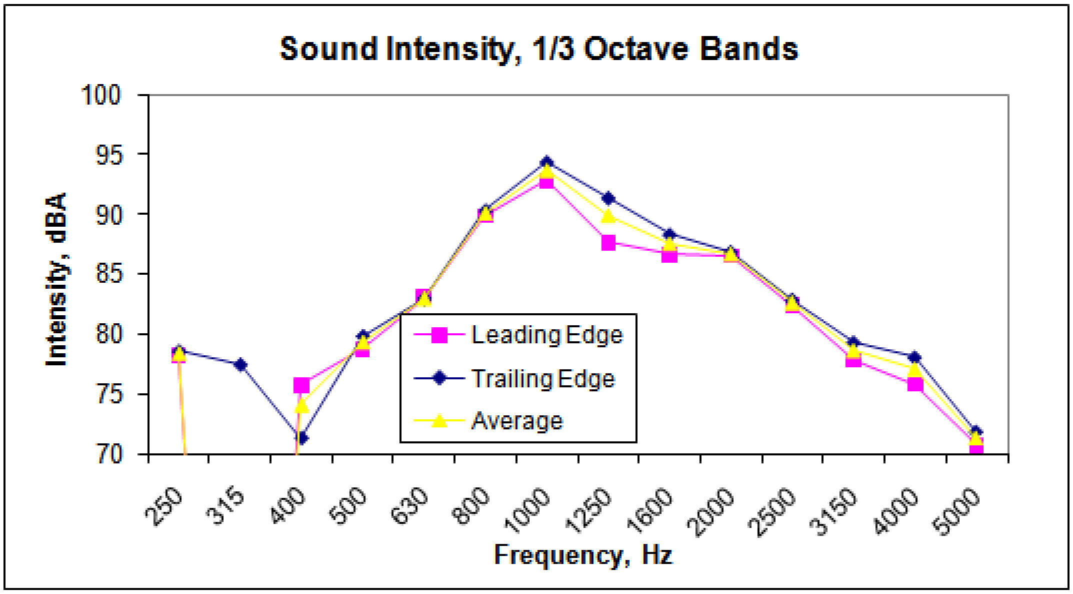


Figure D.64. St. Cloud Test Section WB Innovative Grind Passing Lane Trial 2

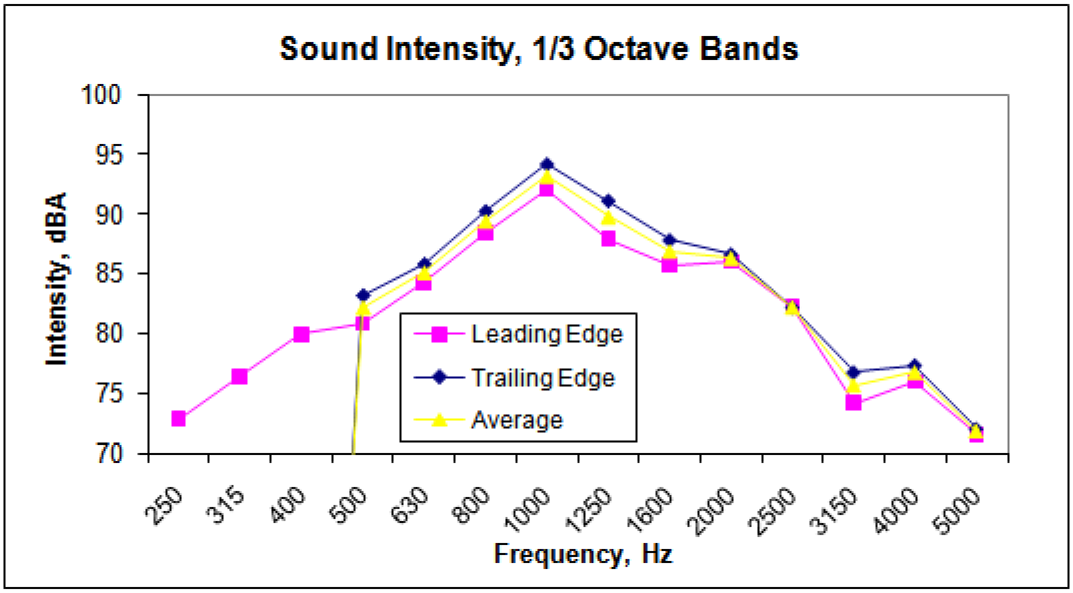


Figure D.65. St. Cloud Test Section WB Innovative Grind Passing Lane Trial 3

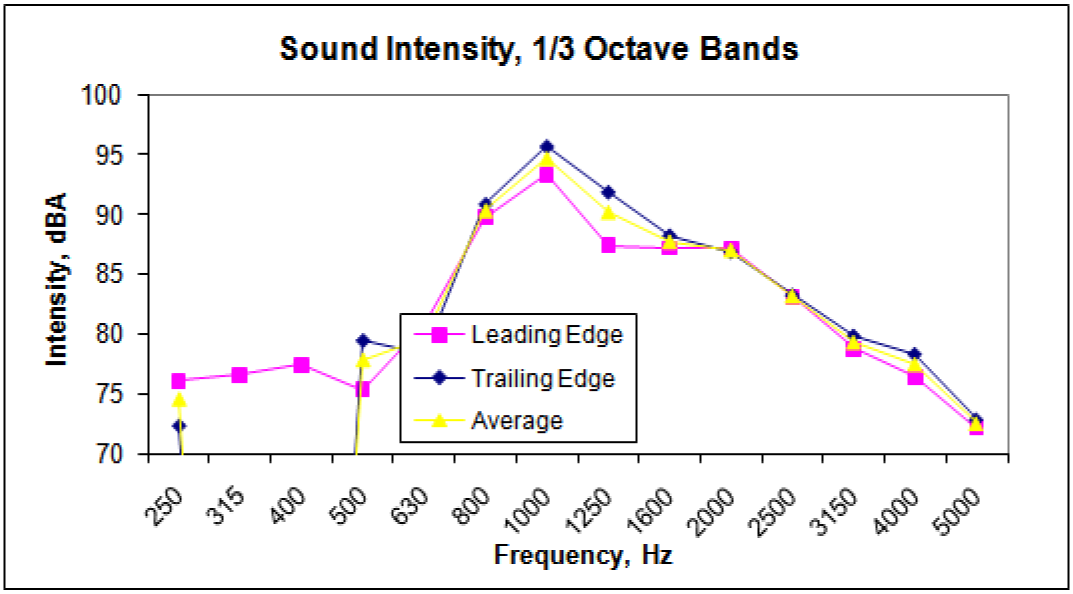


Figure D.66. St. Cloud Test Section WB +500 Innovative Grind Passing Lane Trial 1

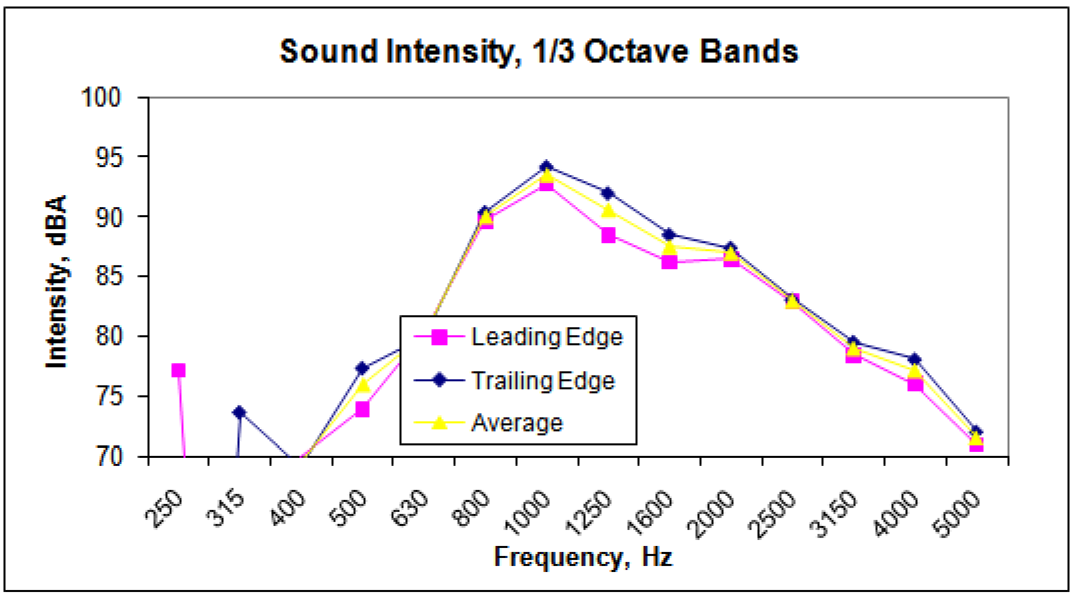


Figure D.67. St. Cloud Test Section WB +500 Innovative Grind Passing Lane Trial 2

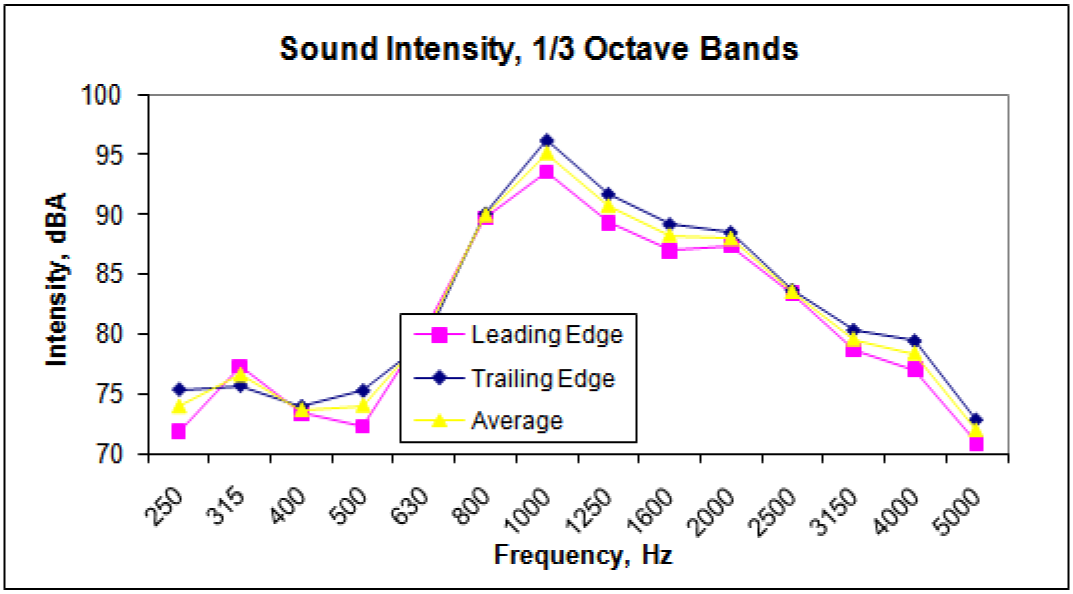


Figure D.68. St. Cloud Test Section WB +500 Innovative Grind Passing Lane Trial 3

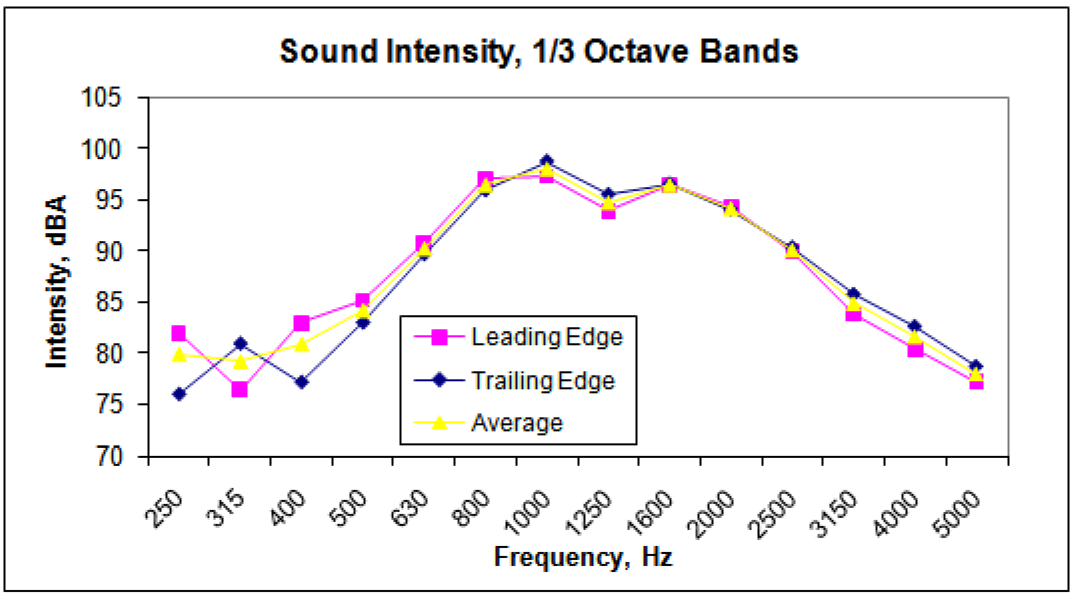


Figure D.69. St. Cloud Test Section Control Driving Lane Trial 1

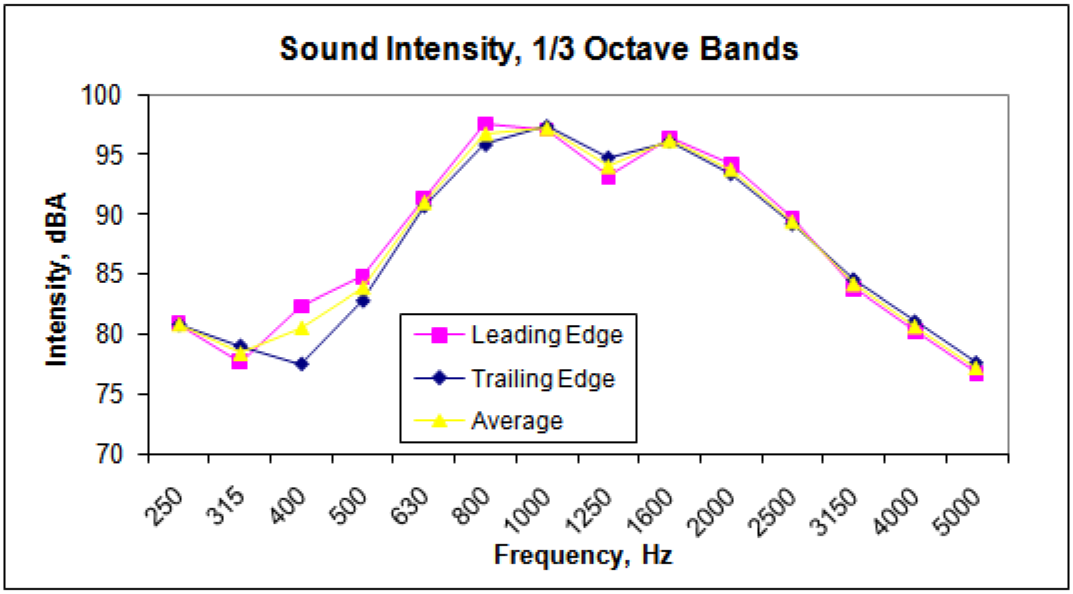


Figure D.70. St. Cloud Test Section Control Driving Lane Trial 2

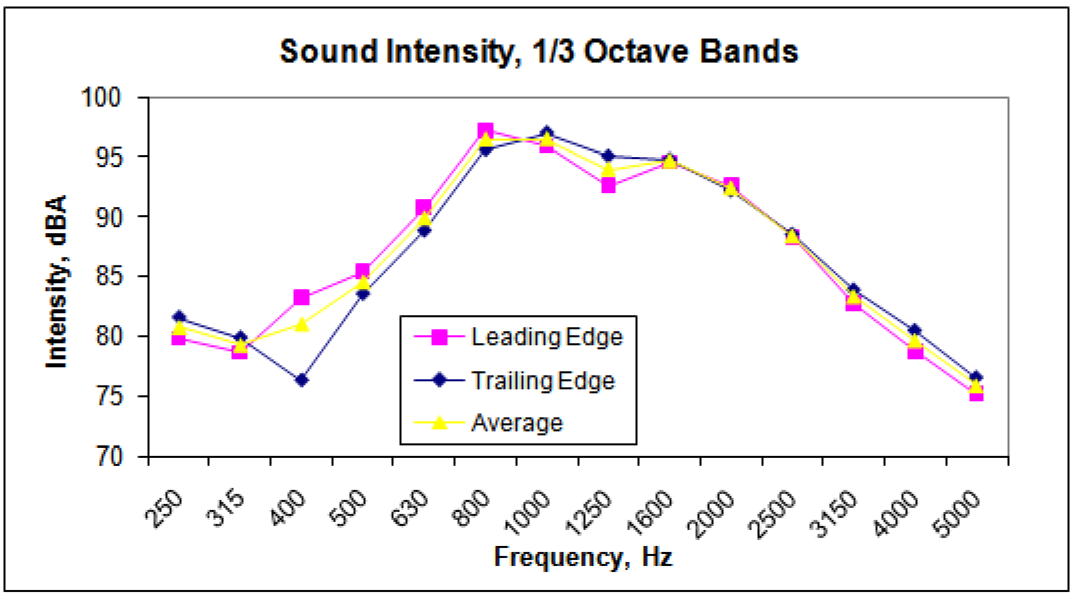


Figure D.71. St. Cloud Test Section Control Driving Lane Trial 3

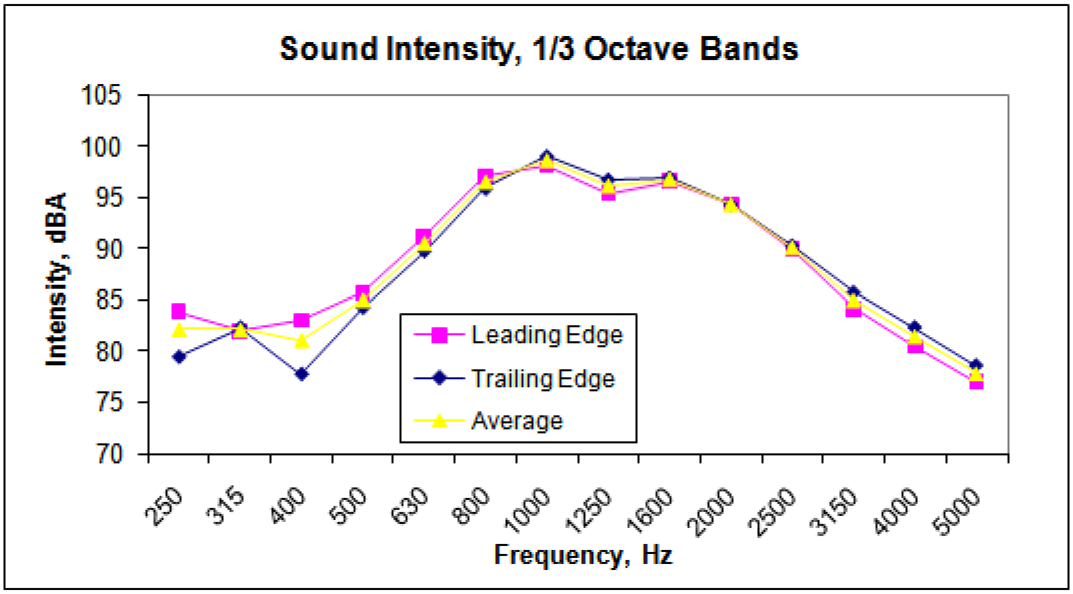


Figure D.72. St. Cloud Test Section Control +500 Driving Lane Trial 1

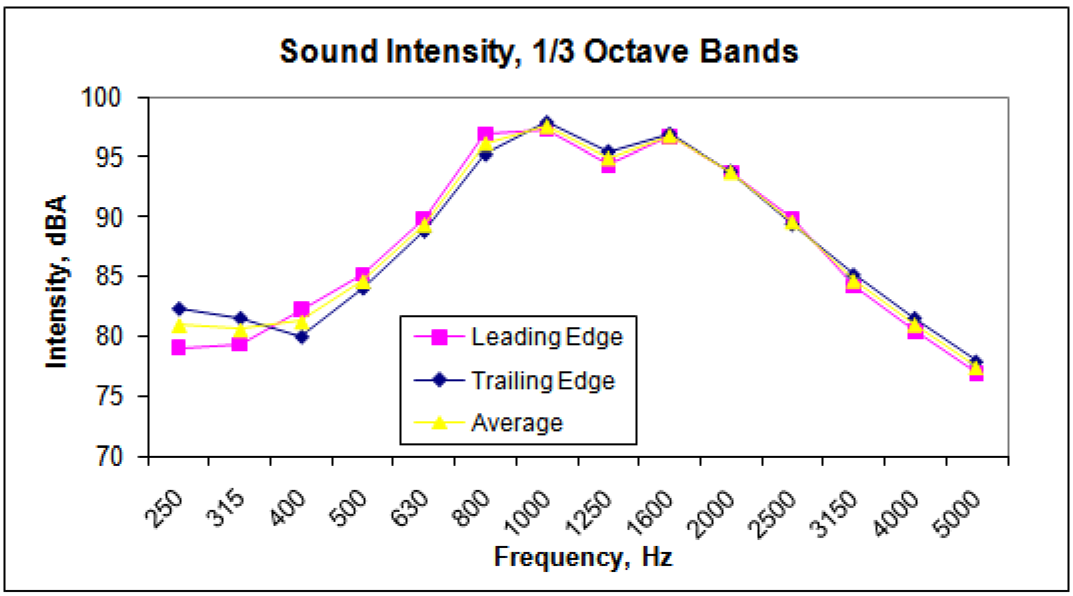


Figure D.73. St. Cloud Test Section Control +500 Driving Lane Trial 2

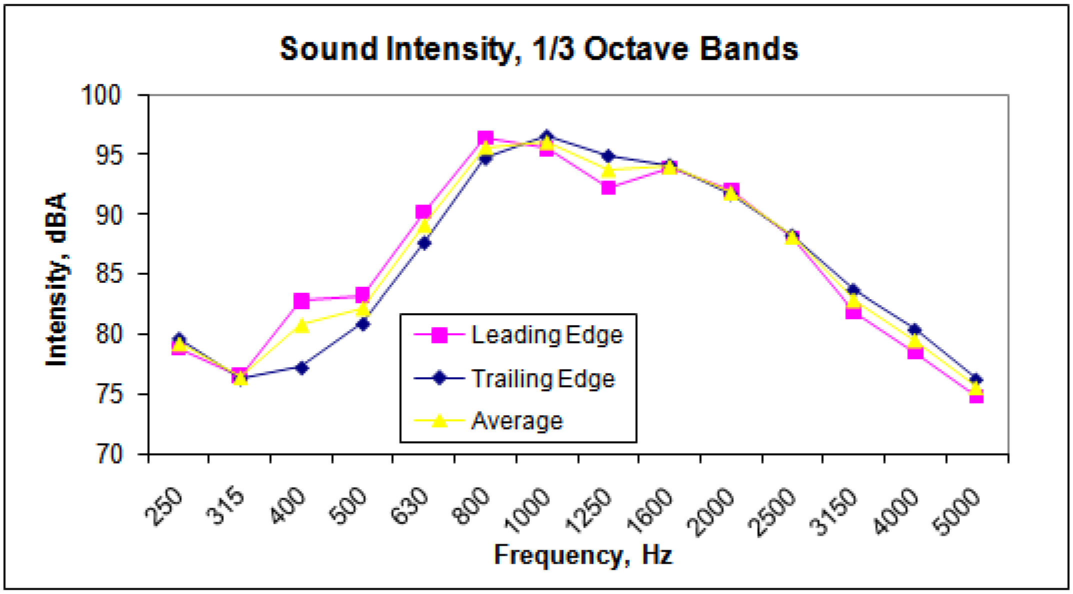


Figure D.74. St. Cloud Test Section Control +500 Driving Lane Trial 3

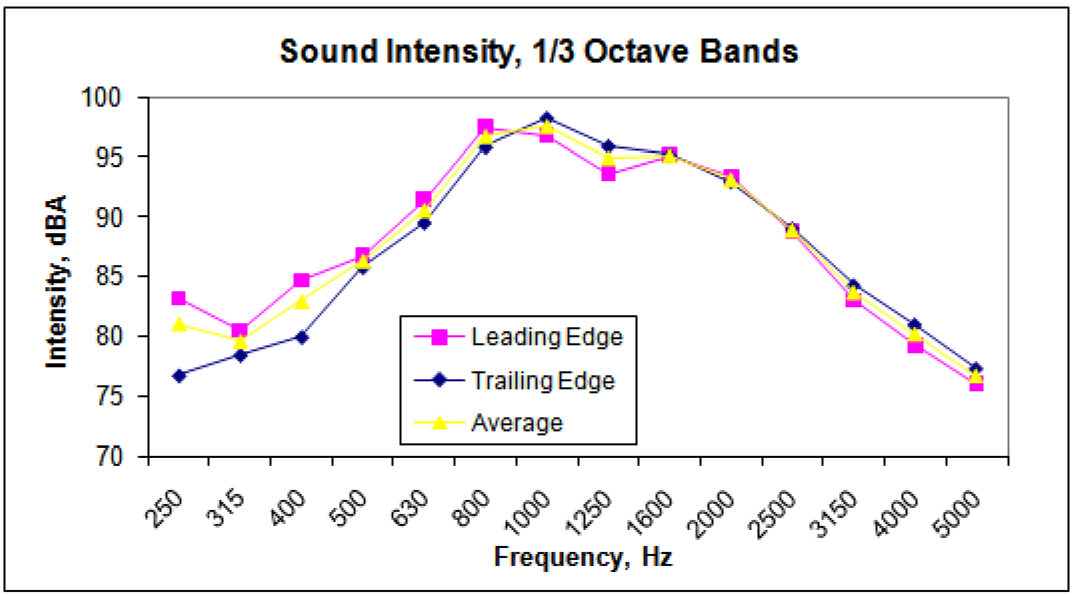


Figure D.75. St. Cloud Test Section Control Passing Lane Trial 1

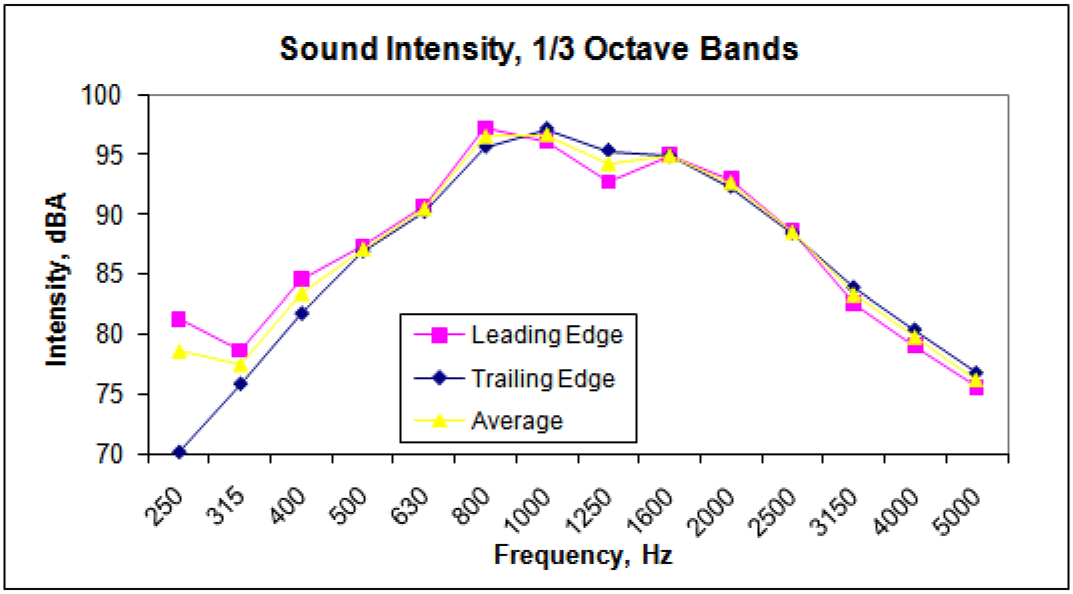


Figure D.76. St. Cloud Test Section Control Passing Lane Trial 2

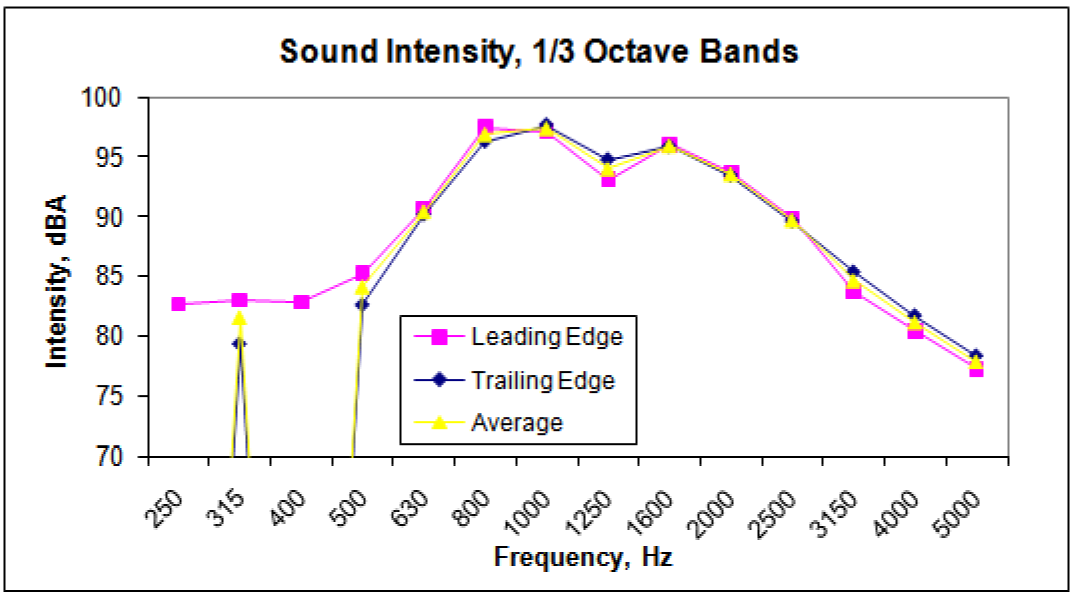


Figure D.77. St. Cloud Test Section Control Passing Lane Trial 3

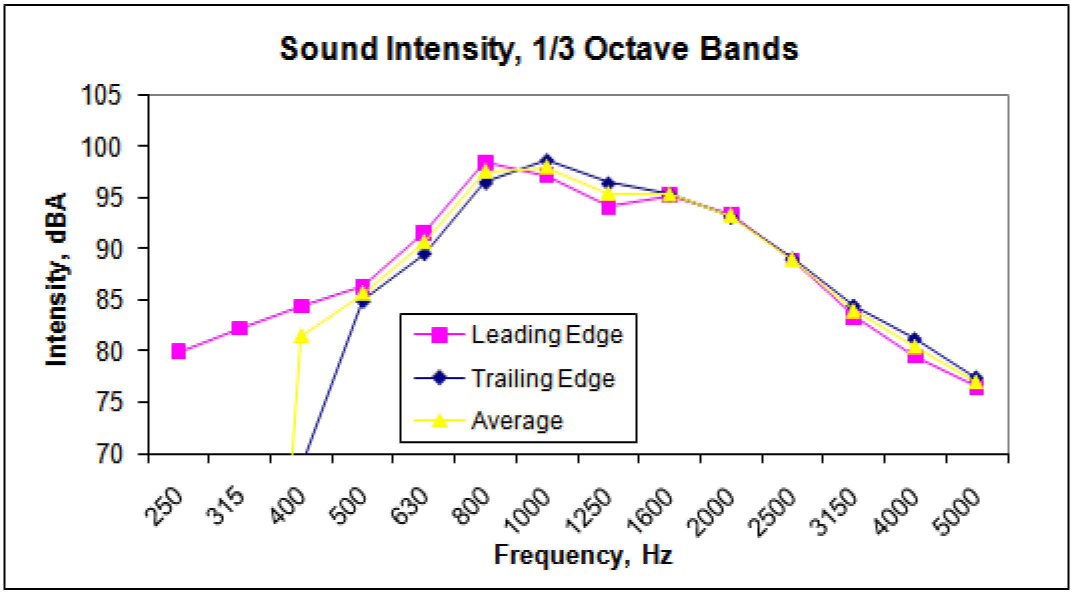


Figure D.78. St. Cloud Test Section Control +500 Passing Lane Trial 1

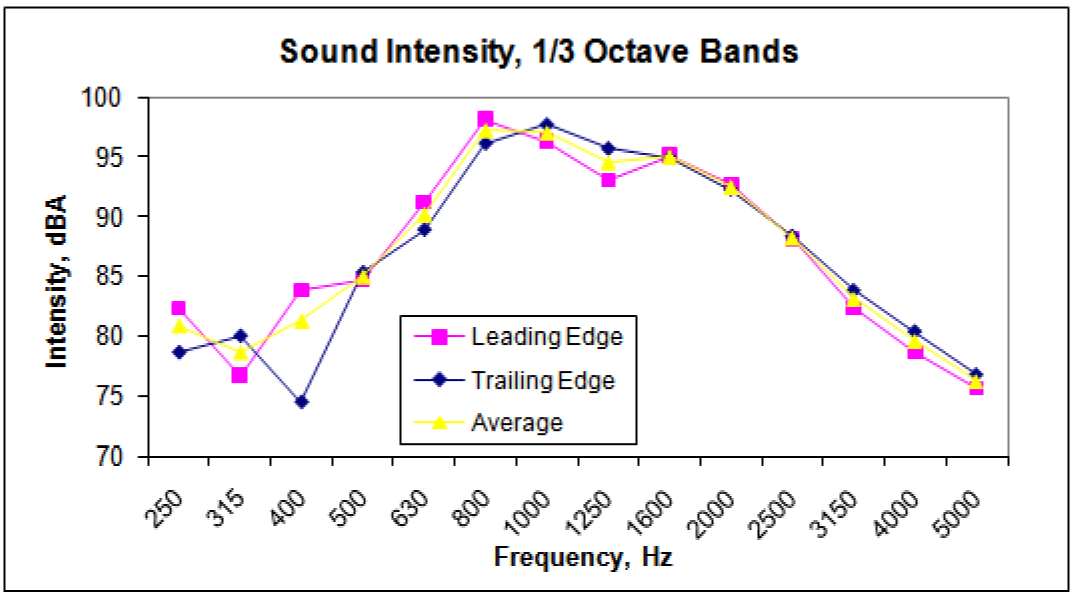


Figure D.79. St. Cloud Test Section Control +500 Passing Lane Trial 2

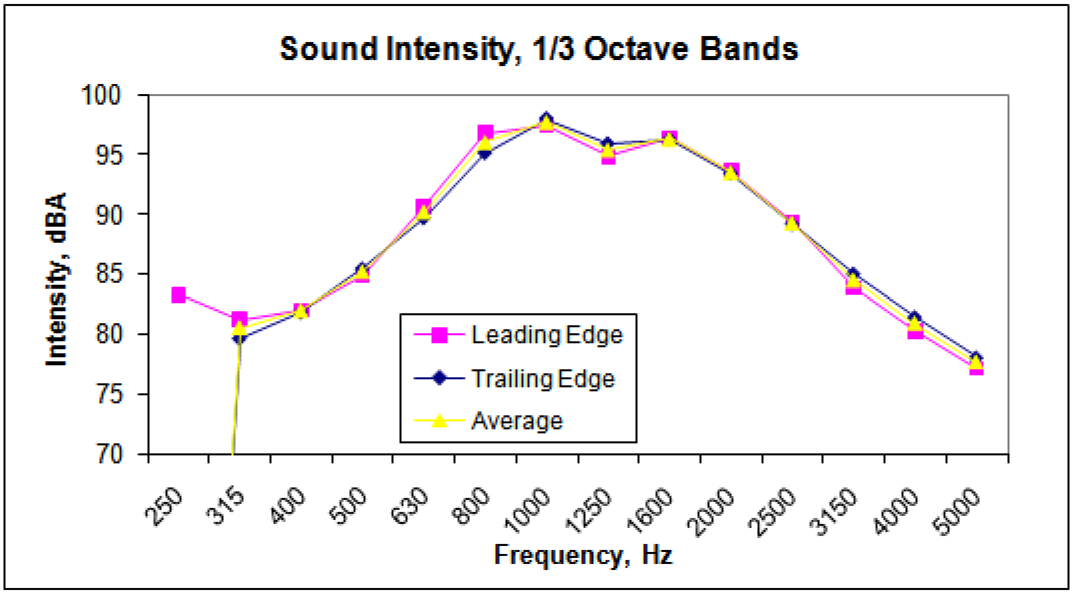


Figure D.80. St. Cloud Test Section Control +500 Passing Lane Trial 3