
Research Report – UCD-ITS-RR-14-28

Comparative OBSI Testing in Northern California: The Davis Rodeo

December 2014

Paul Donovan

Comparative OBSI Testing in Northern California: The Davis Rodeo

Authors:

Paul R. Donavan, Sc.D.

Part of Partnered Pavement Research Program (PPRC) Strategic Plan Element 4.39:
Continued Monitoring of Selected Quieter Pavement Test Sections

PREPARED FOR:

California Department of Transportation
Division of Research, Innovation, and System
Information
Office of Roadway Research

PREPARED BY:

Illingworth & Rodkin, Inc.
Petaluma, CA



DOCUMENT RETRIEVAL PAGE		UCPRC Reprint Report No.: UCPRC-RP-2014-01							
Title: Comparative OBSI Testing in Northern California: The Davis Rodeo									
Author: Paul R. Donavan									
Caltrans Technical Leads and Reviewers: Bruce Rymer, Linus Motumah, Rupinder Dosanjh									
Prepared for: California Department of Transportation, Division of Research, Innovation, and System Information	FHWA No.: CA152380A	Date Work Submitted: January 2013	Date: January 2013						
Strategic Plan Element No.: 4.39	Status: Stage 6, final version	Version No.: 1							
<p>Abstract: This is a reprint of a report written for Caltrans and the University of California Pavement Research Center as part of Partnered Pavement Research Program Strategic Plan Number 4.39, the continued monitoring of selected quieter pavement test sections. The goal of this program is to identify quieter, smoother, safer, and more durable pavement surfaces. The report describes a series of comparative OBSI tests in a so-called “rodeo” performed on 19 different pavement sections by three different teams and vehicles using five different tires to determine variations among them for noise testing, following the AASHTO TP 76 procedure. The testing considered the tires’ rubber durometer hardness, tread depth, and accumulated mileage, and measured sound levels using the on-board sound intensity method. The results of these measurements are compared with similar testing performed earlier, and showed that the average differences measured by the teams were smaller and the maximum OBSI ranges were larger than those made in earlier testing.</p>									
<p>Keywords: tire noise, pavement noise, OBSI, on-board sound intensity, rubber durometer hardness, tread depth, tire mileage</p>									
<p>Proposals for Implementation: Continue testing using current test procedures and procedures for monitoring tire condition and changing tires as warranted by condition.</p>									
<p>Related Documents:</p> <ul style="list-style-type: none"> • A. Ongel, J. Harvey, E. Kohler, Q. Lu, and B. D. Steven. (2008) Investigation of Noise, Durability, Permeability, and Friction Performance Trends for Asphaltic Pavement Surface Types: First- and Second-Year Results. (UCPRC-RR-2007-03) • Q. Lu, E. Kohler, J. Harvey, and A. Ongel. (2009) Investigation of Noise and Durability Performance Trends for Asphaltic Pavement Surface Types: Three-Year Results. (UCPRC-RR-2009-01) • Q. Lu, J. Harvey, and R. Wu. (2011) Investigation of Noise and Durability Performance Trends for Asphaltic Pavement Surface Types: Four-Year Results. (UCPRC-RR-2010-05) • A. Rezaei, J. Harvey, and Q. Lu. (2012) Investigation of Noise and Ride Quality Trends for Asphaltic Pavement Surface Types: Five-Year Results. (UCPRC-RR-2012-04) • A. Rezaei and J.T. Harvey. (2013) Investigation of Noise, Ride Quality and Macrotexture Trends for Asphalt Pavement Surfaces: Summary of Six Years of Measurements. (UCPRC-RR-2013-11) • E. Kohler and J. Harvey. (2011) Quieter Pavement Research: Concrete Pavement Tire Noise. (UCPRC-RR-2010-03) • A. Rezaei and J. Harvey. (2012) Quieter Pavement Research: Concrete Pavement Tire Noise: Third-Year Results Report (UCPRC-RR-2012-03) • A. Rezaei and J. Harvey. (2013) Concrete Pavement Tire Noise: Fourth-Year Results (UCPRC-RR-2013-12) • I.M. Guada, A. Rezaei, J.T. Harvey, and D. Spinner. (2012) Evaluation of Grind and Groove (Next Generation Concrete Surface) Pilot Projects in California. (UCPRC-RR-2013-01) 									
<p>Signatures:</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 25%; padding: 10px;">P. Donavan First Author</td> <td style="width: 25%; padding: 10px;">J. T. Harvey Technical Reviewer</td> <td style="width: 25%; padding: 10px;">J. T. Harvey Principal Investigator</td> <td style="width: 25%; padding: 10px; text-align: center;">Bruce Rymer Linus Motumah Caltrans Technical Leads</td> <td style="width: 25%; padding: 10px; text-align: center;">T. J. Holland Caltrans Contract Manager</td> </tr> </table>					P. Donavan First Author	J. T. Harvey Technical Reviewer	J. T. Harvey Principal Investigator	Bruce Rymer Linus Motumah Caltrans Technical Leads	T. J. Holland Caltrans Contract Manager
P. Donavan First Author	J. T. Harvey Technical Reviewer	J. T. Harvey Principal Investigator	Bruce Rymer Linus Motumah Caltrans Technical Leads	T. J. Holland Caltrans Contract Manager					

DISCLAIMER STATEMENT

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by the California Department of Transportation (Caltrans) of any product described herein.

For individuals with sensory disabilities, this document is available in braille, large print, audiocassette, or compact disk. To obtain a copy of this document in one of these alternate formats, please contact: the California Department of Transportation, Division of Research Innovation, and Systems Information, MS-83, P.O. Box 942873, Sacramento, CA 94273-0001.

TABLE OF CONTENTS

COMPARATIVE OBSI TESTING IN NORTHERN CALIFORNIA: THE DAVIS RODEO.....	1
Introduction.....	2
Test Description	2
Test Sites.....	2
Test Equipment	4
Test Vehicles.....	5
Test Tires	6
Test Procedures	6
Test Matrix.....	7
Test Results.....	7
Overall Levels – Day 1	7
Overall Levels – Day 2	10
One-Third Octave Band Levels	12
Summary.....	16
References.....	16
Appendix.....	18

COMPARATIVE OBSI TESTING IN NORTHERN CALIFORNIA:

THE DAVIS RODEO



Prepared for:

**University of California
Pavement Research Center**

Prepared by:

**Paul R. Donavan, Sc.D.
Illingworth & Rodkin, Inc.
Petaluma, CA**

January 29, 2013

INTRODUCTION

On October 10 and 11, 2012, comparative on-board sound intensity measurements (OBSI) were made on 19 different sites on roads in the Davis, California area. Three groups participated in these measurements including personnel from the University of California Pavement Research Center (PRC), the International Grooving and Grinding Association (IGGA), and Illingworth & Rodkin, Inc. (IR). A total of five test tires were used allowing for tire swaps between test teams. Some of the test sites had been used in previous comparative testing between IR and PRC as well as other groups. However, since the time of those tests, the PRC has migrated to a new test vehicle and a new OBSI analyzer. The purpose of this report is to document the results from the 2012 Rodeo and also to compare the results to previous rodeos and to the precision and bias statements of the latest version of the American Association of State Highway Transportation Officials (AASHTO) TP 76 procedure for measuring OBSI [1]. A complete listing of the OBSI results is provided in the Appendix.

TEST DESCRIPTION

Test Sites

The sites were grouped into two loops with the intent that the testing at each loop would be completed simultaneously by all three teams before moving to the next loop. The locations of the sites in Loop 1 are shown in Figure 1. Several of these sites have been used in previous comparative testing including 2, 3, 5, 6, 8, and 9. In addition, sites 3, 5, 6, and 8 have been routinely used by PRC for on-going calibration. Specific information on each site in Loop 1 is

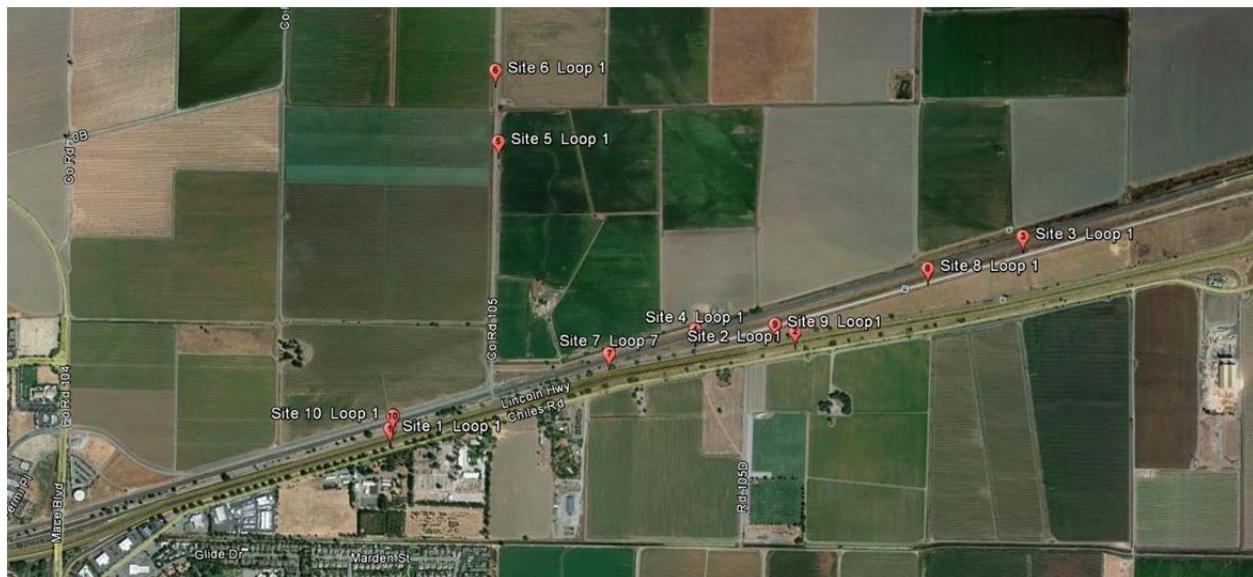


Figure 1: Location of test sites on Rodeo Loop 1

provided in Table 1. The length of Loop 1 was 12.9 miles resulting in an approximate test time of 15 minutes per circuit given stops and turnarounds. The loop began at the Mace Road

Table 1: Information for test sites on Rodeo Loop #1

Site No.	Roadway	Direction	Pavement Type	Notes
1	I-80	Eastbound	New AC	Recent pavement rehabilitation
2	I-80	Eastbound	Old OGAC	Caltrans long-term test site
3	Co. Rd. 32	Westbound	PCC	UC PRC calibration section
4	Co. Rd. 32	Westbound	New AC	Recent pavement rehabilitation
5	Co. Rd. 105	Northbound	Older Ac	UC PRC calibration section
6	Co. Rd. 105	Southbound	Older Ac	UC PRC calibration section
7	Co. Rd. 32	Eastbound	New AC	Recent pavement rehabilitation
8	Co. Rd. 32	Eastbound	PCC	UC PRC calibration section
9	I-80	Westbound	Old OGAC	Recent pavement rehabilitation
10	I-80	Westbound	New AC	Caltrans long-term test site

entrance onto I-80, followed I-80 eastbound to the Chiles Road exit which loops around to westbound County Road (Co) 32, proceeds northbound on Co 105 past Site 5. After a turnaround farther up Co Rd 105, the loop proceeds southbound to Co Rd 32 eastbound and back on to westbound I-80 to the Mace Road exit.

The nine test sites on Loop 2 are shown in Figure 2. This loop is approximately 6.8 miles in



Figure 2: Location of test sites on Rodeo Loop 2

length and can be traversed in about 9 minutes with turnarounds. Information on these sites is provided in Table 2. This loop begins southbound on State Route (SR) 113 from the Lincoln

Table 2: Information for test sites on Rodeo Loop #2

Site No.	Roadway	Direction	Pavement Type	Notes
1	SR 113	Southbound	Older PCC	Surface to be groiund
2	SR 113	Southbound	Newer AC	Recent pavement rehabilitation
3	I-80	Westbound	Older AC	AC surface on bridge deck
4	I-80	Westbound	New AC	Recent pavement rehabilitation
5	I-80	Eastbound	New AC	Recent pavement rehabilitation
6	SR 113 Ramp	Eastbound	Older PCC	Bridge deck
7	SR 113 Ramp	Eastbound	Newer AC	Recent pavement rehabilitation
8	SR 113	Northbound	PCC	Initial grinding completed
9	SR 113	Northbound	Older AC	On exit ramp

Highway ramp, proceeds southbound exiting on to westbound I-80, proceeds on I-80 to the Kidwell Road exit used as a turnaround to eastbound I-80. After two sites on eastbound I-80, the loop follows northbound SR 113 back to the Lincoln Highway exit for a turnaround back onto the loop.

Prior to October 10, 2012, preliminary OBSI measurements were made on the candidate sites. These results indicated that a range in level of about 9 dB was produced. The results of the rodeo confirmed that this range was achieved.

Test Equipment

All three teams used similar OBSI fixtures, microphones, and preamplifiers to acquire the sound pressure signals needed to measure sound intensity. These are shown mounted on test vehicles for each team in Figure 3. Each team did use different analyzers to process the signals into sound intensity levels. IGGA uses a five-channel Brüel & Kjaer PULSE system to produce the leading and trailing edge probe signals into sound intensity levels. PRC uses a four-channel Harmonie box built into a Soundbook computer as produced by Sinus Messtechnik GmbH. IR uses a National Instruments (NI) analogue to digital converter to acquire four signals and processes these in a laptop computer using LabView software to obtain the sound intensity levels. This NI system also uses an external four-channel G.R.A.S. microphone power supply that in turn feeds into the computer. Prior to the on-road measurements, a bench-top comparison of the data acquisition/processing systems was completed using a G.R.A.S. Type 51AB Intensity Calibrator and the differences between systems was found to be negligible.

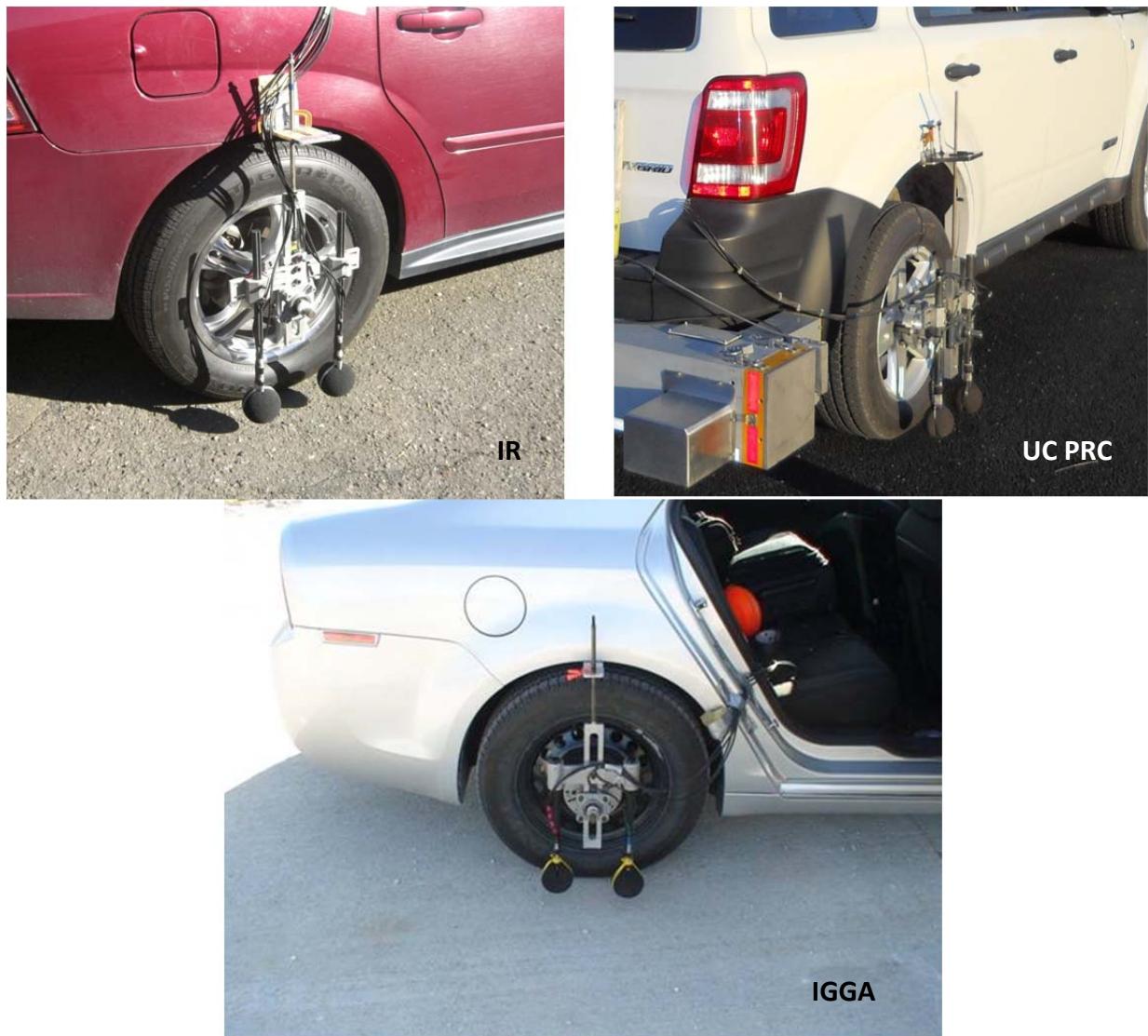


Figure 3: OBSI fixtures on IR, UC PRC, and IGGA test vehicle

Test Vehicles

The test teams each used different vehicles for their measurements. IGGA used a rented 2012 Chevrolet Malibu, PRC used their standard 2008 Ford Escape, and IR used their usual 2005 Chevrolet Malibu for the testing. Prior to the on-road test, the loading on the right rear test tire was measured for each team using a portable scale. The operators that were to be used in the testing were also included in these measurements. The loading for the IGGA vehicle was 748 lbs on the right rear tire, 795 lbs for the IR vehicle, and 979 lbs for the PRC vehicle. The higher loading for the PRC vehicle was due the inherent heavier vehicle, the pavement profiler added at the rear bumper, and the additional instrumentation carried in the vehicle for other types of pavement tests. Both the IGGA and IR vehicles provide test tire loading within the 800 ± 100 lbs stated in AASHTO TP 76 while the PRC was 79 lbs over this range. However, in order to

minimize the effects of test tire loading the camber on the right rear tire was set to be neutral in the loaded condition.

Test Tires

A total of five tires were tested in the rodeo on various vehicles. The tires are identified in Table 3 along with their properties of build week, durometer hardness number, and tread depth. From Table 3 data, none of these tires could be considered as “new”. Based on the recently completed

Table 3: Test tires and properties

Test Tire	Build Date	Durometer Hardness Number	Tread Depth
UCD PRC	Week 30 2011	71	6.7 mm
IGGA Old Tire	Week 8 2006	75	6.8 mm
IGGA New Tire	Week 46 2008	67	7.4 mm
IR NC Rodeo Tire	Week 18 2009	69	7.3 mm
IR SRTT 3# Tire	Week 43 2007	68	7.3 mm

NCHRP Project 1-44 (1) [2], replacement of SRTT test tires should be considered whenever several of the following conditions are met:

1. The age of the test tire measured from the time of construction is more than 5 years
2. The test tire has an accumulated mileage greater than 11,000 mi (17,700 km)
3. The durometer hardness of the tire is greater than 70
4. The average tread depth is less than 7.2 mm (0.28 in)

The only parameter that was not well known for the five tires was their accumulated mileage. The IGGA New tire, the IR NC Rodeo tire, and the IR SRTT #3 tire are all known to have mileage much less than 11,000 miles. The UC PRC and IGGA Old tires may be approaching or exceeding this limit and based on the other data and criteria, replacement of these tires may be appropriate.

Test Procedures

The procedures used by each team were consistent with the AASTHO TP 76 procedure. The test speed in all cases was 60 mph which was monitored by GPS for IR, by a wheel pulse encoder for UC PRC, and by the vehicle speedometer for IGGA after calibration with GPS data. Five second (i.e. 440 ft long) averages were measured at each test site and three runs were typically done and averaged together for the reported OBSI levels. The acoustic instrumentation systems were calibrated with a 1,000 Hz and 94.0 dB cal tone before each test session on each test day. Prior to the first set of tests, the setups of the probes were verified to be within the limits set in TP 76 for height above pavement, distance to the tire, and separation. The tires were also checked for

air pressure prior to beginning testing and were all confirmed or set to be at 30 psi cold. Cones were used to mark the beginning of each test section and triggering of the analyzer was done manually as the front bumper passed the cone. Location in the wheel path was done visually by the vehicle operators.

Test Matrix

The test matrix for the two days is shown in Table 4. After the first day of testing, a cold front moved into the area dropping the temperature considerably. As a result, the closest comparisons that could be made between the teams for each day did not consider the effect of the temperature. The IGGA old tire was tested on both days as the results of October 10th could

Table 4: Test matrix by day, time, temperature, and tires

Date/Test	Loop	Time of day	Temp. Degrees F	Tire Tested by Teams		
				IGGA	UC PRC	IR
Oct. 10						
Test 1	2	2:35 PM	79	IGGA Old	UC PRC	IR NC
Test 2	1	4:20 PM	81	IGGA Old	UC PRC	IR NC
Oct. 11						
Test 1	2	11:00 AM	62	IGGA Old	IR NC	IGGA New
Test 2	2	1:15 PM	69	IGGA New	IR SRTT #3	IGGA Old

be exported from the PULSE system at the time. The UC PRC tire was mounted on a wheel with a bolt pattern that did not align with the Malibu vehicles and could not be swapped for comparisons. The UC PRC tests were delayed from the others on October 11th in order to adapt the UC PRC OBSI fixture to the wheels to which the IR tires were mounted.

TEST RESULTS

Overall Levels – Day 1

The overall OBSI levels measured on October 10th for Loop 1 are shown in Figure 4. For these sites, the UC PRC results are typically lower than the other teams with the average difference being 0.4 dB lower than IR and 0.9 dB lower than IGGA. The range in OBSI levels between the teams was calculated on each site. The maximum range was found to be 1.7 dB and average range for all sites was 1.0 dB with a standard deviation of 0.5 dB. For the Loop 2 results in Figure 5, the levels for the UC PRC tend to be slightly higher than the other two although there is some variation in the rank ordering of the teams between the different pavements. For Loop 2, the UC PRC levels average 0.4 dB higher than IGGA and 0.8 dB higher than IR. For these data, the maximum range was 1.7 dB while the average range was 1.1 dB with a standard deviation of 0.5 dB. Since the two loops were measured at almost the same air temperature, they can be

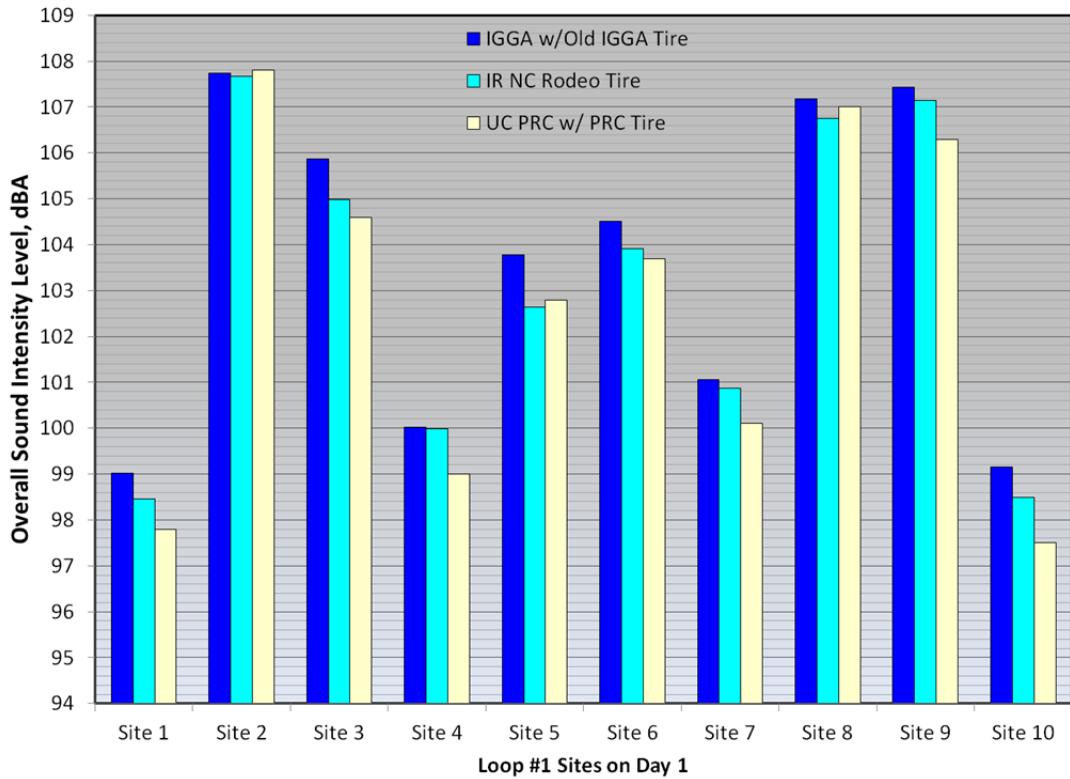


Figure 4: Overall OBSI levels for all teams on Loop 1 measured October 10th

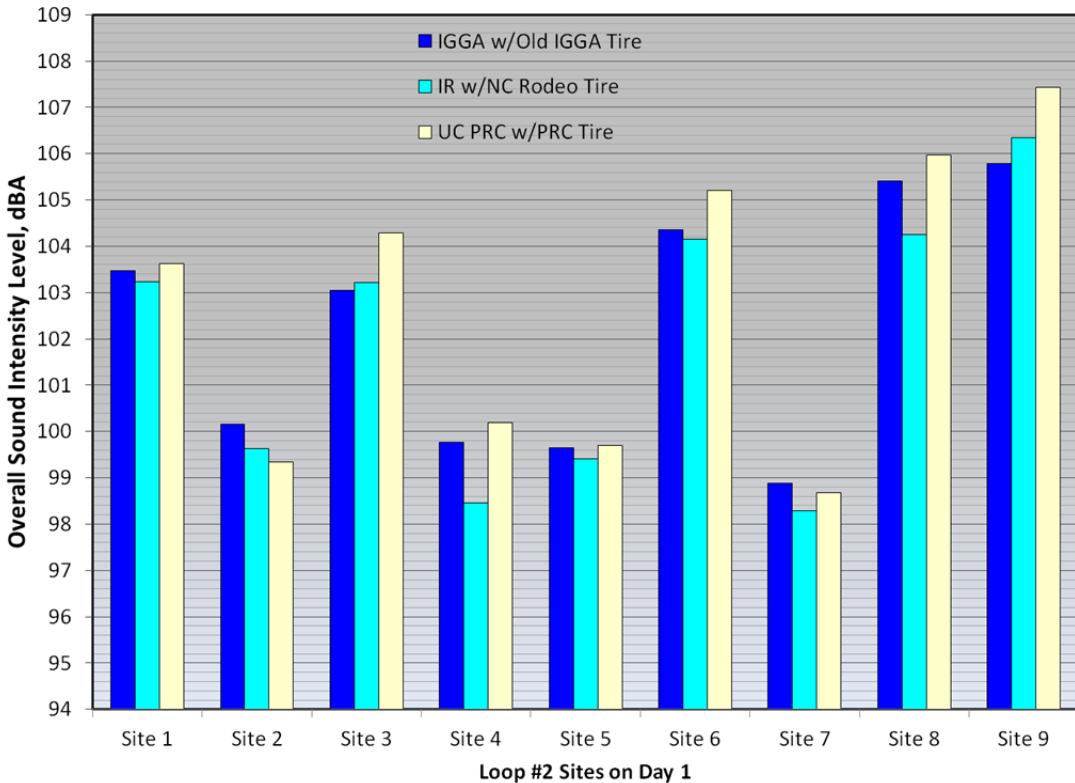


Figure 5: Overall OBSI levels for all teams on Loop 2 measured October 10th

combined to consider directly the statistics of both data sets. The results from the two loops are plotted in Figure 6 in which the individual data points are plotted against the average of the three teams for each measurement site. Compared to the average of all teams, the average for the UC

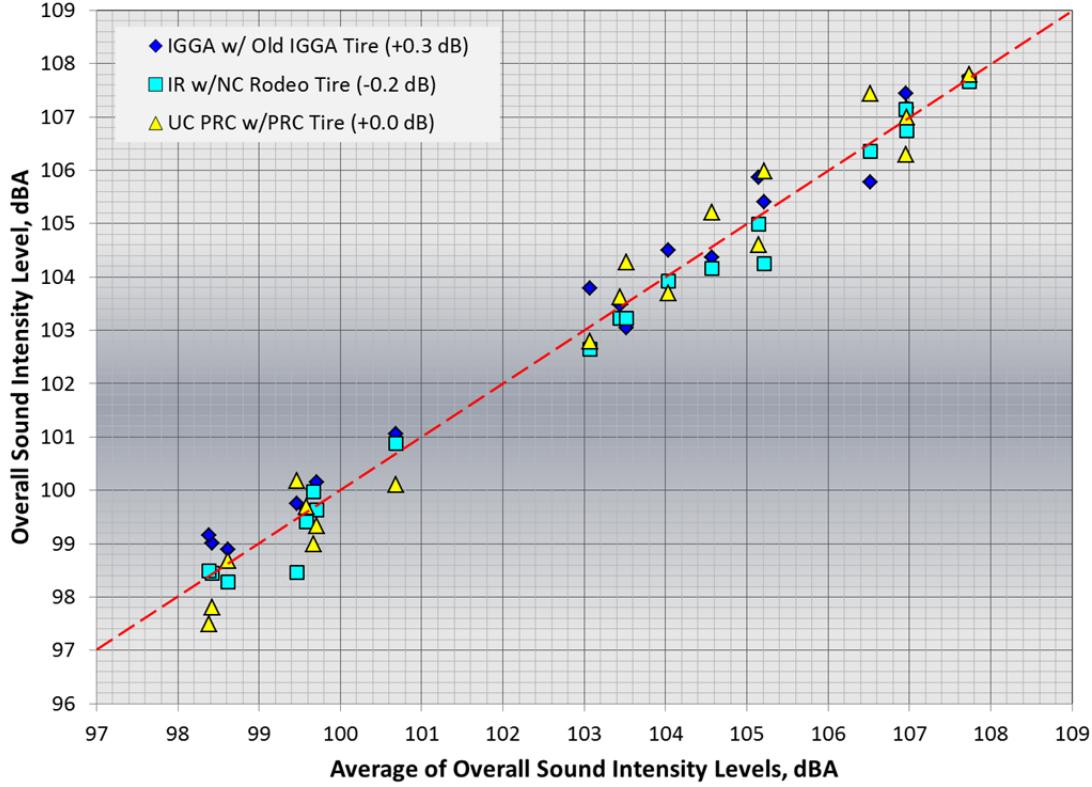


Figure 6: Plot of overall OBSI levels for each team vs. the average of teams at each test site

PRC levels is equal to the average of all teams while the IR average is 0.2 dB less and the IGGA average is 0.3 dB greater for a total range of 0.5 dB. The statistics for combined loops of this Davis Rodeo are compared to previous rodeos [3] in Table 5. The average difference or average range for the Davis Rodeo was lower than the previous rodeos by 0.2 dB to 0.5 dB. The standard deviation is similar to the others and maximum range is lower by 0.3 to 1.2 dB. The statistics are also well within the range of precision and bias statements of the TP 76 procedure.

Table 5: Comparison of measurement team statistics for the Davis Rodeo to previous rodeos

Rodeo Event	Average Difference, dB	Standard Deviation, dB	Maximum Range, dB	Number of Teams
Davis Rodeo	1.0	0.5	1.7	3
NC Rodeo Day 1	1.2	0.5	2.3	4
NC Rodeo Day 2	1.5	0.4	2.4	5
Mesa Rodeo	1.3	0.5	2.2	4
Texas Rodeo	1.3	0.4	2.0	3
Yuma Rodeo	1.3	0.4	2.1	2
NCAT Rodeo	1.4	1.1	2.9	2

The average difference between the three test tires considering all sites is consistent with the aging parameters dependencies from the NCHRP Project 1-44-1 results and those bulleted in the “Test Tires” section. The IGGA Old tire produced the highest average OBSI level, it had the highest durometer rubber hardness number and the largest number of years since production, and it was almost equal to the UC PRC tire in (lack) of tread depth. The IR NC Rodeo tire was constructed more recently than the IGGA Old tire, has a hardness number 6 less, and 0.5 mm more tread depth. In between in noise level, the UC PRC tire has a hardness number in between the other two tires, the most recent construction date, and a tread depth about equal to the IGGA tire. Any effect of higher loading on the UC PRC test tire is not discernible in the results of the Loop 1 and 2 measurements. In the NCHRP Project 1-44-1, the rate of increase in OBSI with added loading was found to be 0.21 dB/100 lb on average with the rates varying somewhat for different pavements. The effects of loading may have reduced for the UC PRC vehicle by neutralized chamber angle.

Overall Levels – Day 2

From Table 4, the temperatures on October 11th were about 10 to 18°F cooler than the day before. From the temperature gradient of -0.04 dB/°F, the measured levels for the same tire would be about 0.4 to 0.7 dB higher on October 11th. From the results shown in Figure 7 for the IGGA testing on both days, the levels on the warmer day are actually slightly higher averaging about 0.2 dB higher. Data for the two-day comparison were not normalized for temperature for two reasons: normalizing the temperatures for these pavements did not improve the results, and the change in temperature was relatively small. Figure 7 also provides a comparison of the old IGGA tire and new(er) IGGA tire on October 11th with a temperature difference of only 7° F. As would be expected from the data of Table 3, the levels for the newer tire were slightly lower

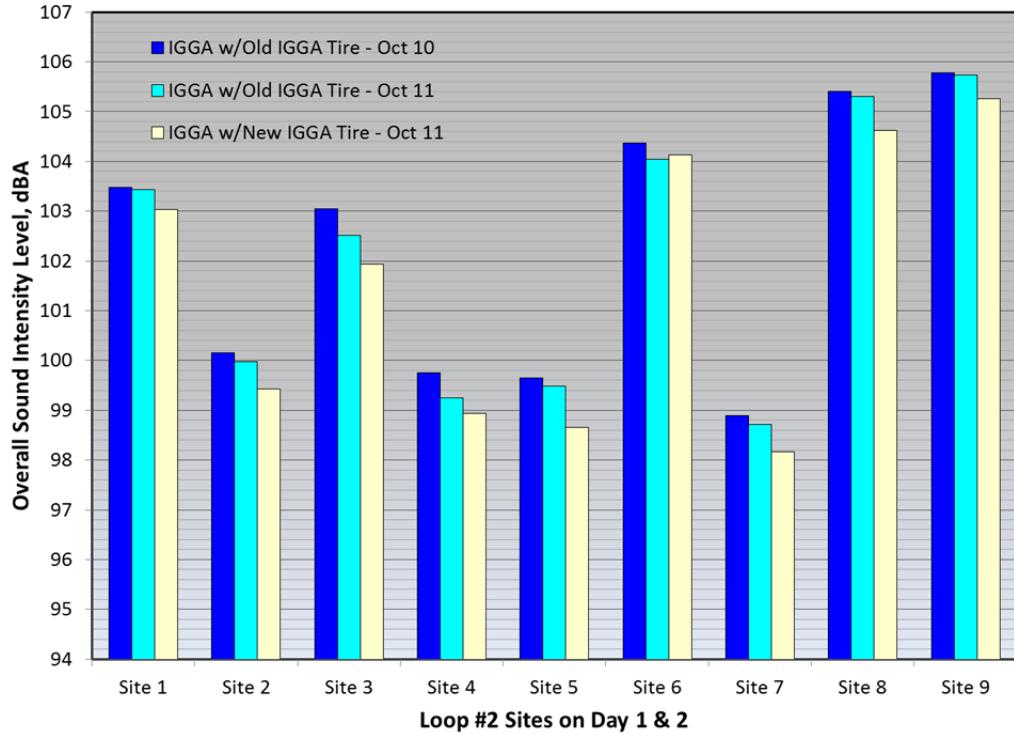


Figure 7: Overall OBSI levels for new and old IGGA tires tested on the IGGA vehicle

(0.5 dB) than the older tire. This is consistent with the finding from the NCHRP Project 1-44-1 in which older tires as a group were found to average 0.4 dB higher in level than the average of a group of new tires. In the NCHRP study, it was also determined that OBSI level increases at rate of 0.055dB/hardness number. With the hardness number difference of 8 for the old and new IGGA tires, the expected increase would be 0.4 dB which compares well to the measured increase from this rodeo. The decreased tread depth of the Old IGGA tire could also contribute slightly (less than 0.1 dB) to the higher noise levels as decreasing tread depth is expected to increase overall level by 0.106 dB/mm [2]. This same tire comparison was made on the IR vehicle on October 11th producing a somewhat different result. Without taking temperature into account, the newer tire was measured to be 0.1 dB higher than the older tire. When temperature was taken into account, this trend was reversed with the older tire being 0.2 dB higher in level. Accounting for temperature, this trend is reversed with the older tire being 0.2 dB higher in level. The levels measured with the IR test vehicle were also higher than those measured on the IGGA vehicle for the respective tests measured on October 11th with an average difference for the old tire of 0.5 dB and 1.1 dB for the newer tire.

Several more comparisons are shown in Figure 8 which includes all of the data from for UC PRC vehicle and results for the NC Rodeo tire tested on both the IR and UC PRC vehicles. As with

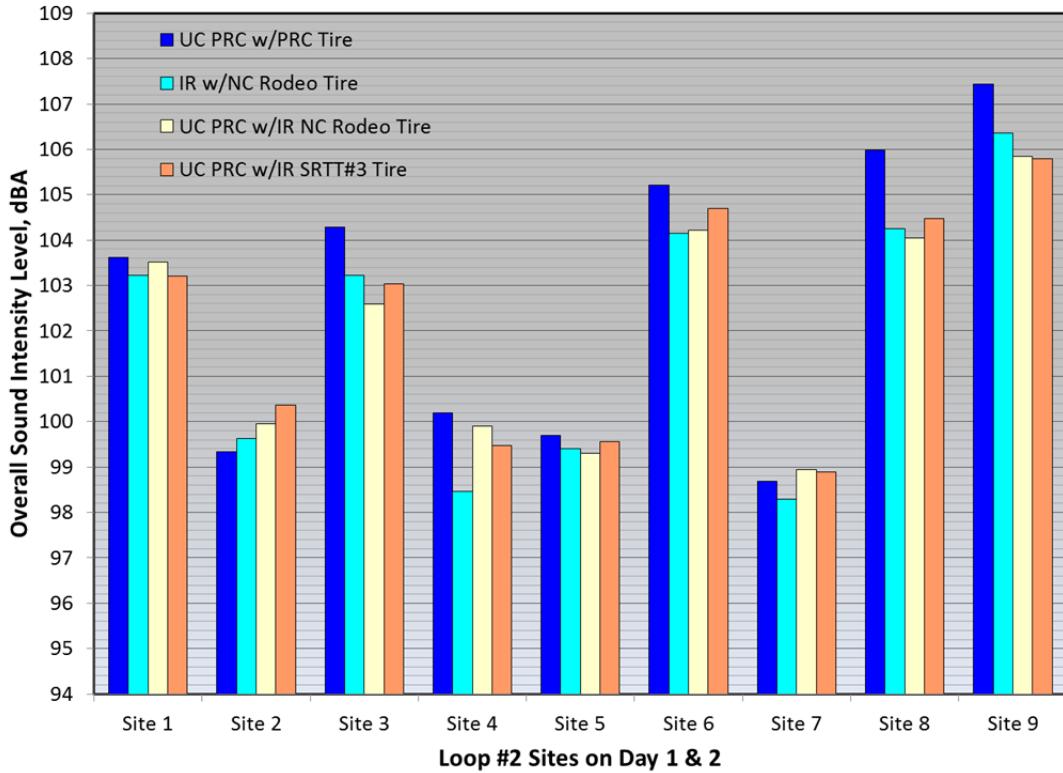


Figure 8: Overall OBSI levels measured on UC PRC & IR test vehicles

the results in general, these data vary in rank ordering with pavement, for example, Site 2 shows the opposite rank order of the tires/vehicles on Site 9. In general, the UC PRC tire on the UC PRC vehicle tends to produce higher levels than the other cases. Considering the UC PRC vehicle only, the UC PRC tire is 0.7 dB and 0.5 dB higher than the NC Rodeo tire and SRTT #3 respectively. From Table 3, this is not unexpected as the NC tire and SRTT #3 have lower hardness numbers than the UC PRC tire and more tread depth. Even though the PRC tire is newer, its accumulated mileage is greater than the other tires. In comparing the NC Rodeo tire measured on the IR and UC PRC vehicles, the levels are very similar with an average difference of only 0.1 dB. This further supports a conclusion that differences seen between the PRC tire and the other cases is due primarily to the tire itself rather than any vehicle or test team biases.

One-Third Octave Band Levels

The one-third octave band spectra for all ten measurement sites in Loop 1 are shown in Figure 9 as measured by IR with the NC Rodeo tire. As suggested by the range of the overall OBSI

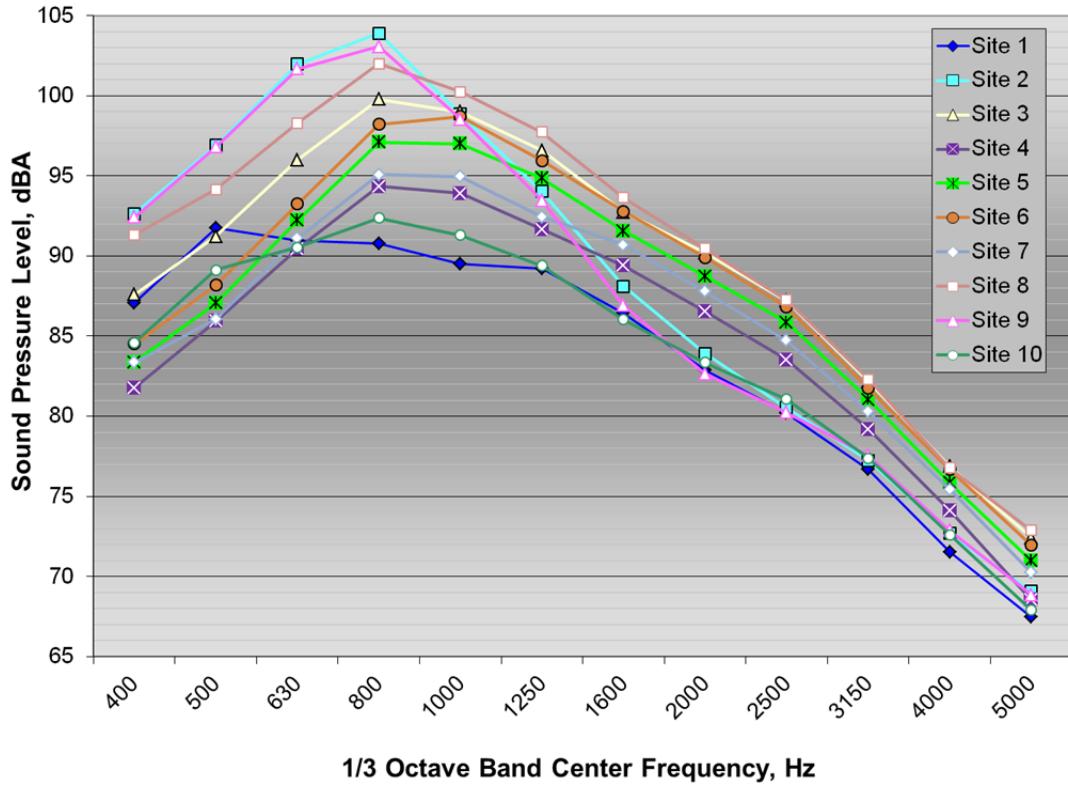


Figure 9: 1/3 octave band levels for Loop 1 measured by IR test car with the NC Rodeo tire

levels, there is also a considerable range in level between the sites on a one-third octave band basis. Below 1250 Hz, the differences range from about 10 dB to 13 dB. In the higher frequencies, the differences are smaller, but still range between 5 dB and 8 dB. For Loop 2, the differences are slightly smaller with the range below 2500 Hz being about 8 dB while the higher frequency range is about the same as the Loop 1 sites. For the Loop 2 pavements in shown in Figure 10, there is a definite grouping of the newer AC sites (2, 4, 5, and 7) with the range for these pavements being about 2 dB or less. These pavements are also lower in level by about 5 to 8 dB for bands above 800 Hz.

Comparing the spectra for each team on each pavement indicated that the results are fairly consistent as typified by the results shown in Figure 11. For Loop 1, the average range in one-third octave level is 1.6 dB with a standard deviation of 0.7 dB. For Loop 2, the average range was somewhat larger at 2.0 dB with a standard deviation of 0.9 dB. As general trend, the levels for IGGA data with the Old IGGA tire were higher than the IR and UC PRC results at 800 Hz and above as shown in Figure 12. This same trend is consistently apparent in comparing the spectra for the new and old IGGA tires as exemplified in Figure 13. This is thought to be due to

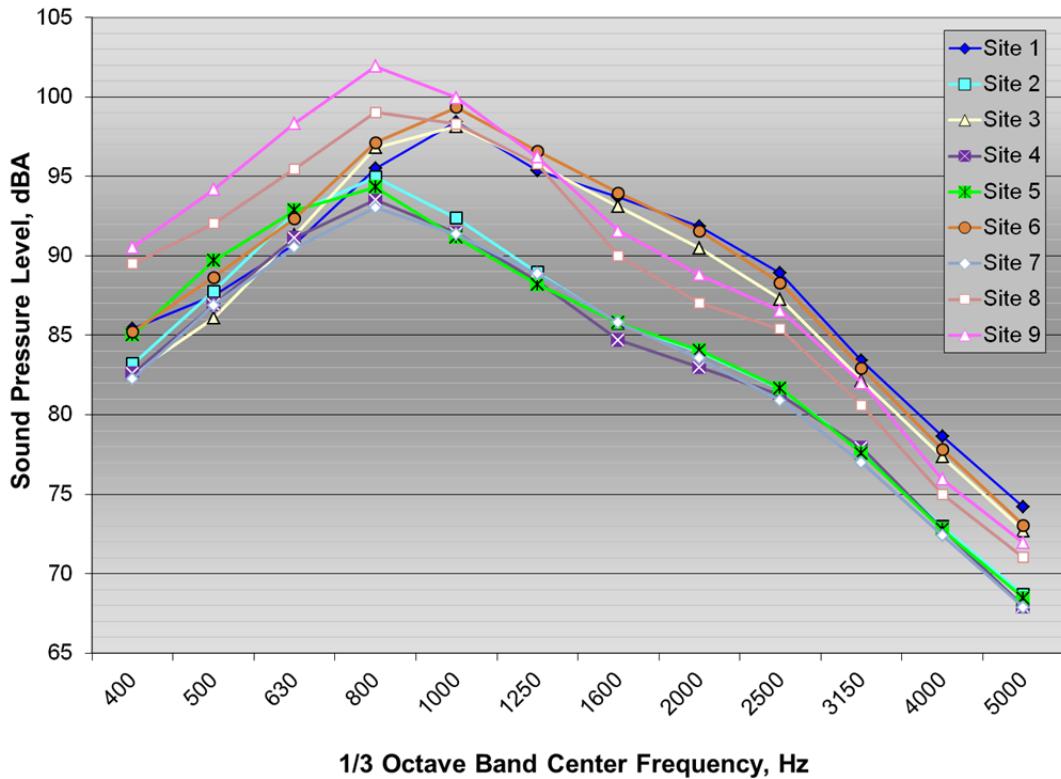


Figure 10: 1/3 octave band levels for Loop 2 measured by IR test car with the NC Rodeo tire

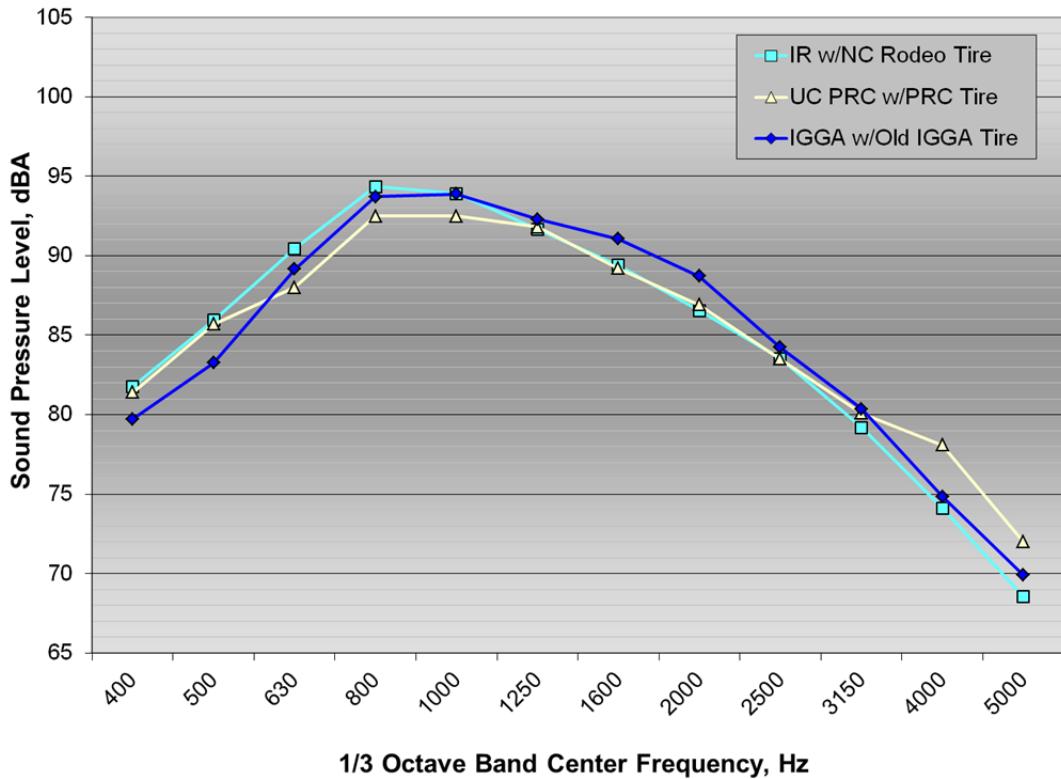


Figure 11: 1/3 octave band levels for all three teams on Site 4 of Loop 1

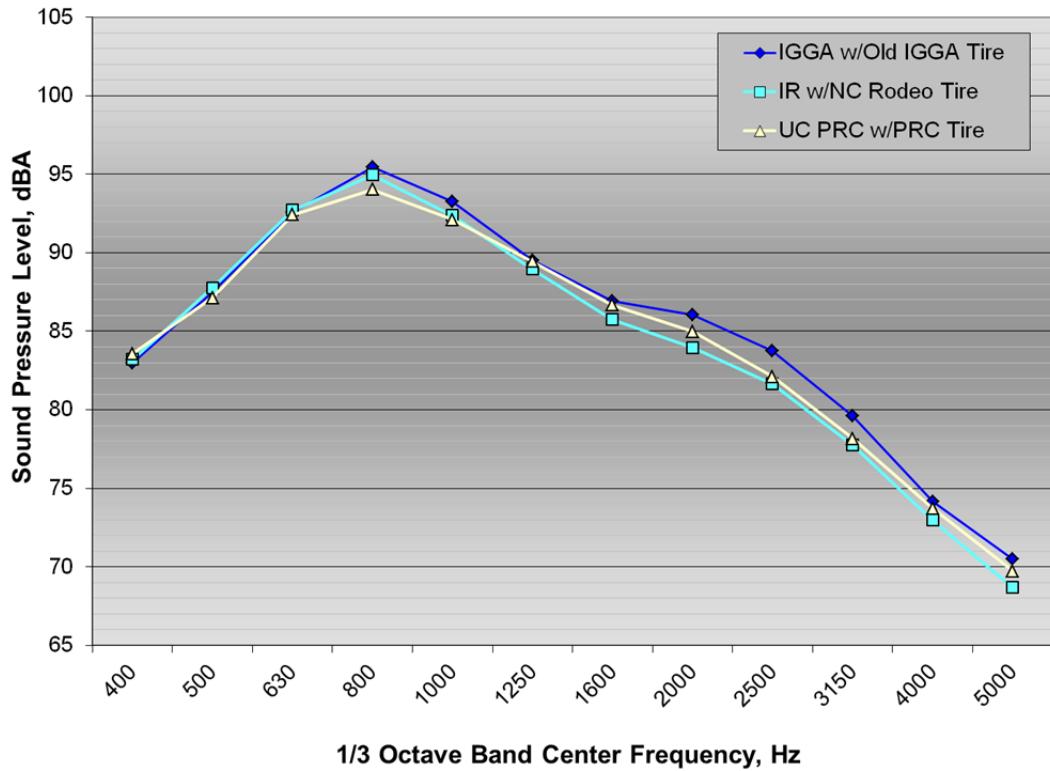


Figure 12: 1/3 octave band levels for all three teams on Site 2 of Loop 2

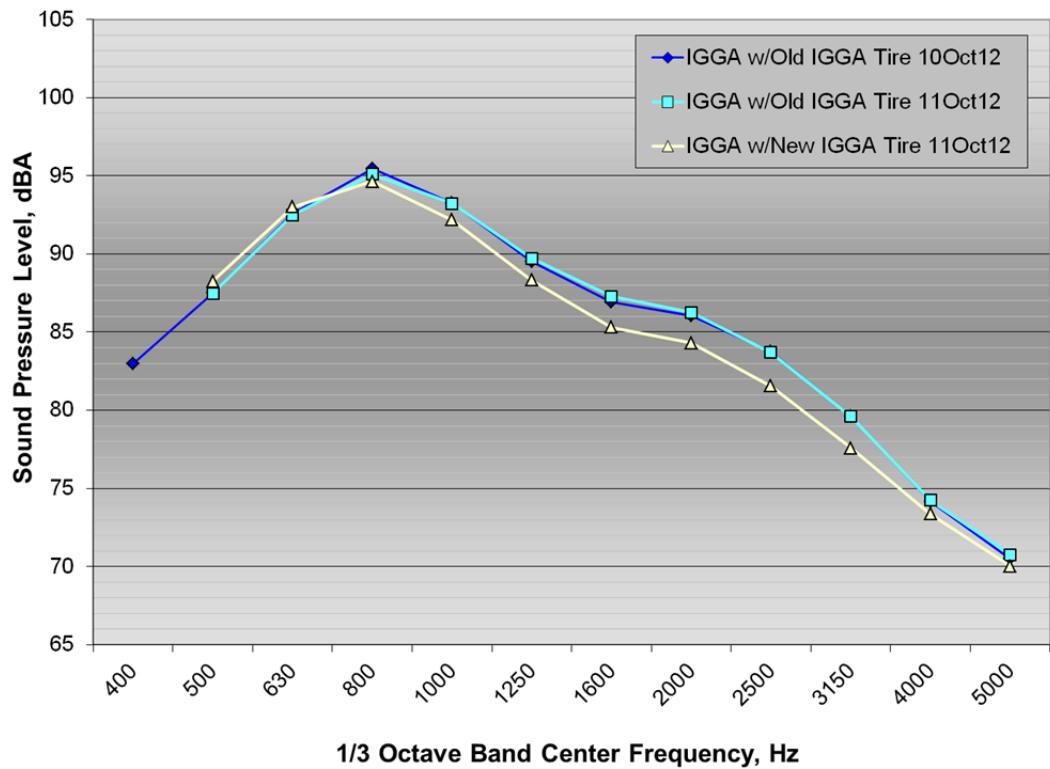


Figure 13: 1/3 octave band levels for old & new IGGA tires on Site 2 of Loop 2

the greater hardness of the older IGGA tire and its effect on the scrubbing mechanism [4,5]. The UC PRC tire also produced one-third octave band levels in the higher frequency bands that fell in between the Old IGGA tire and the NC Rodeo tire (see Figure 12) consistent with its hardness number being in between these other two tires. Figure 13 also provides an indication of test repeatability as the Old IGGA tire was tested on October 10th and 11th producing virtually identical results.

SUMMARY

OBSI comparative testing was performed on 19 different sections by three teams using 5 tires. The measurements were made in general conformance with the AASHTO TP 76 test procedure and results fell within the precise and bias limits of that standard. The average difference between the teams was also smaller than experienced in previous rodeos as was the maximum range. The test tire loading requirement of 800 ± 100 lbs was not achieved by one team, however, this variance did not produce any significant variance with the results of the other test teams. The effect of higher loading on this test tire may have been mitigated by maintaining neutral camber on the tire. Two of the test tires were outside of the limits of the procedure for tire rubber durometer hardness, tread depth, and possibly accumulated mileage. These two tires did produce levels slightly higher (0.2 dB and 0.5 dB) on average than those that were within the requirements. Direct comparison of two tires, one that did meet the requirements of TP 76 and one that did not, produced an average difference of 0.5 dB consistent with the findings of the NCHRP Project 1-44-1 results for the effects of tire aging. Although there was a temperature difference of about 15° F between the two test days, direct comparison of the same tire by the same test team indicated an average difference of 0.2 dB. As a result the reported levels were not normalized for temperature.

REFERENCES

1. Standard Practice for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method, TP 76-13, American Association of State Highway and Transportation Officials, 444 North Capitol Street N.W., Suite 249, May 2012. Washington, D.C. 20001.
2. Donavan, P., and Lodico, D., “Measuring Tire-Pavement Noise at the Source: Precision and Bias”, Draft Final Report to the National Cooperative Highway Research Program (NCHRP) on Project 1-44 (1), July 14, 2011.
3. Donavan, P., “Comparative OBSI Testing in North Carolina: The North Carolina Rodeo”, prepared for the Tire/Pavement Noise Research Consortium Pooled Fund TPF -5 (135), prepared by Illingworth & Rodkin, Inc., Petaluma, California, March 2011
4. Donavan, P. and Rymer, B., “Effects of Aging on Tire/Pavement Noise Generation for Concrete Pavements of Different Textures”, Transportation Research Record, Journal of the Transportation Research Board, No. 2233, Environment 2011, pp 152-160

5. B. Rymer, P. Donavan, and E. Kohler, "Tire/Pavement Noise Levels Related To Roadway Friction Improvement", Compendium of Papers, TRB 89th Annual Meeting, Washington, D.C., January 2010.

APPENDIX

This appendix presents the one-third octave band and overall OBSI levels for all the measurements performed in the rodeo. The results for Loop 1 on October 10th are presented first followed by the results for Loop 2 also for the 10th. The results for Loop 2 on October 11th follow.

Table A1: OBSI levels for IR with the NC Rodeo tire on Loop 1, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
400	87.1	92.6	87.6	81.8	83.4	84.5	83.4	91.3	92.4	84.6
500	91.8	96.9	91.2	85.9	87.1	88.2	86.1	94.1	96.8	89.1
630	91.0	102.0	96.0	90.4	92.2	93.2	91.1	98.3	101.7	90.5
800	90.8	103.9	99.8	94.3	97.1	98.2	95.1	102.0	103.1	92.4
1000	89.5	98.9	99.0	93.9	97.0	98.7	95.0	100.2	98.5	91.3
1250	89.2	94.0	96.6	91.7	94.9	96.0	92.4	97.7	93.5	89.4
1600	86.4	88.1	92.7	89.4	91.6	92.8	90.7	93.6	86.9	86.0
2000	82.9	83.9	90.2	86.5	88.7	89.9	87.8	90.5	82.7	83.3
2500	80.2	80.5	87.2	83.5	85.9	86.8	84.7	87.2	80.2	81.1
3150	76.7	77.2	82.1	79.2	81.0	81.8	80.3	82.3	77.6	77.4
4000	71.5	72.7	76.9	74.1	75.9	76.7	75.4	76.8	72.9	72.6
5000	67.5	69.1	72.4	68.5	71.0	72.0	70.3	72.9	68.8	67.9
A-wtd	98.4	107.7	105.0	100.0	102.6	103.9	100.9	106.7	107.1	98.5

Table A2: OBSI levels for UC PRC with the PRC tire on Loop 1, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
400	87.4	92.0	87.6	81.4	86.2	88.1	83.4	90.2	91.0	85.3
500	91.9	95.7	89.8	85.7	87.0	88.7	86.7	93.3	95.1	88.9
630	89.8	100.8	94.7	88.0	92.8	93.8	89.2	99.0	99.4	87.4
800	90.2	104.1	99.0	92.5	97.8	99.0	93.4	102.3	102.2	89.5
1000	88.5	100.9	98.8	92.5	96.9	97.6	93.7	100.4	99.8	90.2
1250	87.8	95.6	96.8	91.8	93.3	93.2	92.6	97.6	94.3	90.4
1600	85.2	88.2	93.7	89.2	92.5	93.6	90.6	94.9	86.8	86.5
2000	83.0	84.6	89.9	86.9	89.6	90.3	87.6	91.5	84.3	83.9
2500	79.7	80.5	87.2	83.5	85.3	86.2	84.0	88.1	80.8	81.1
3150	76.0	76.8	82.0	80.1	80.3	81.3	81.1	82.6	77.4	77.5
4000	72.6	73.5	78.0	78.1	77.8	78.6	79.1	78.5	74.1	74.3
5000	69.3	70.5	74.7	72.0	74.6	75.9	73.5	75.3	71.0	70.8
A-wtd	97.8	107.8	104.6	99.0	102.8	103.7	100.1	107.0	106.3	97.5

Table A3: OBSI levels for IGGA with the Old IGGA tire on Loop 1, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
400	87.1	92.6	87.6	81.8	83.4	84.5	83.4	91.3	92.4	84.6
500	91.8	96.9	91.2	85.9	87.1	88.2	86.1	94.1	96.8	89.1
630	91.0	102.0	96.0	90.4	92.2	93.2	91.1	98.3	101.7	90.5
800	90.8	103.9	99.8	94.3	97.1	98.2	95.1	102.0	103.1	92.4
1000	89.5	98.9	99.0	93.9	97.0	98.7	95.0	100.2	98.5	91.3
1250	89.2	94.0	96.6	91.7	94.9	96.0	92.4	97.7	93.5	89.4
1600	86.4	88.1	92.7	89.4	91.6	92.8	90.7	93.6	86.9	86.0
2000	82.9	83.9	90.2	86.5	88.7	89.9	87.8	90.5	82.7	83.3
2500	80.2	80.5	87.2	83.5	85.9	86.8	84.7	87.2	80.2	81.1
3150	76.7	77.2	82.1	79.2	81.0	81.8	80.3	82.3	77.6	77.4
4000	71.5	72.7	76.9	74.1	75.9	76.7	75.4	76.8	72.9	72.6
5000	67.5	69.1	72.4	68.5	71.0	72.0	70.3	72.9	68.8	67.9
A-wtd	98.4	107.7	105.0	100.0	102.6	103.9	100.9	106.7	107.1	98.5

Table A4: OBSI levels for IR with the NC Rodeo tire on Loop 2, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	85.4	83.2	82.6	82.6	85.0	85.2	82.3	89.5	90.5
500	87.5	87.8	86.1	86.9	89.7	88.6	86.9	92.0	94.2
630	90.7	92.7	91.3	91.1	92.9	92.3	90.5	95.5	98.3
800	95.5	95.0	96.8	93.5	94.3	97.1	93.0	99.0	101.9
1000	98.5	92.4	98.1	91.4	91.2	99.4	91.4	98.3	99.9
1250	95.3	89.0	95.8	88.4	88.2	96.6	88.9	95.8	96.2
1600	93.7	85.7	93.1	84.7	85.8	93.9	85.8	90.0	91.6
2000	91.8	84.0	90.5	83.0	84.1	91.6	83.6	87.0	88.8
2500	88.9	81.7	87.3	81.2	81.7	88.3	80.9	85.4	86.6
3150	83.4	77.7	82.2	77.9	77.6	82.9	77.0	80.6	82.0
4000	78.6	73.0	77.4	72.8	72.8	77.8	72.4	75.0	75.9
5000	74.2	68.7	72.7	67.9	68.5	73.1	67.9	71.0	71.9
A-wtd	103.2	99.6	103.2	98.5	99.4	104.2	98.3	104.2	106.3

Table A5: OBSI levels for UC PRC with the PRC tire on Loop 2, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	86.0	83.6	84.4	84.9	86.3	85.6	83.6	91.5	91.8
500	87.5	87.1	87.0	88.3	90.1	88.5	86.8	93.0	94.4
630	91.4	92.4	93.7	93.3	93.2	93.6	91.4	97.7	99.3
800	97.3	94.0	99.0	95.1	94.1	99.5	93.0	101.6	103.5
1000	98.0	92.1	98.4	93.2	91.1	99.8	91.5	99.3	100.6
1250	95.1	89.4	95.9	90.3	89.1	96.6	89.5	96.9	97.0
1600	94.9	86.7	94.5	85.6	87.1	95.8	86.7	91.1	92.5
2000	92.1	85.0	91.2	83.4	85.2	92.6	84.6	88.1	89.9
2500	88.6	82.1	87.4	81.9	82.3	88.9	81.5	86.1	87.4
3150	83.6	78.2	82.7	79.1	78.2	83.7	77.7	81.2	82.6
4000	79.0	73.7	78.1	74.2	73.6	78.8	73.2	75.9	77.0
5000	74.8	69.7	73.9	69.7	69.7	74.4	69.1	72.3	73.3
A-wtd	103.6	99.3	104.3	100.2	99.7	105.2	98.7	106.0	107.4

Table A6: OBSI levels for IGGA with the Old IGGA tire on Loop 2, Oct. 10, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	83.7	83.0	80.8	83.0	84.8	82.9	82.5	90.2	88.3
500	85.8	87.5	83.9	86.5	89.0	85.9	86.3	92.5	91.2
630	89.3	92.6	89.6	91.1	92.1	90.4	90.4	95.9	95.7
800	94.6	95.5	95.6	94.8	94.2	96.0	93.5	99.7	100.4
1000	97.9	93.2	97.5	93.7	92.2	99.1	92.2	99.9	100.4
1250	96.1	89.5	96.4	91.0	89.5	97.5	89.6	97.3	97.5
1600	95.2	86.9	94.2	86.4	87.6	95.6	87.6	93.1	94.1
2000	94.6	86.1	92.3	83.2	86.1	94.4	85.9	89.7	91.2
2500	90.1	83.7	88.0	81.5	83.2	89.8	82.6	86.7	88.0
3150	84.3	79.6	82.4	79.1	78.8	83.8	78.4	82.1	83.5
4000	79.0	74.2	76.9	73.9	73.6	78.1	73.4	75.5	77.0
5000	75.4	70.5	72.9	69.7	70.2	74.1	69.5	72.6	73.6
A-wtd	103.5	100.2	103.0	99.8	99.7	104.4	98.9	105.4	105.8

Table A7: OBSI levels for IR with the New IGGA tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	86.0	83.0	84.4	85.0	86.3	85.6	83.6	91.5	91.8
500	87.5	86.6	87.0	88.7	90.1	88.5	86.8	93.0	94.4
630	91.4	91.8	93.7	93.7	93.2	93.6	91.4	97.7	99.3
800	97.3	93.6	99.0	95.6	94.1	99.5	93.0	101.6	103.5
1000	98.0	91.9	98.4	93.5	91.1	99.8	91.5	99.3	100.6
1250	95.1	89.5	95.9	90.6	89.1	96.6	89.5	96.9	97.0
1600	94.9	86.6	94.5	85.5	87.1	95.8	86.7	91.1	92.5
2000	92.1	84.9	91.2	83.1	85.2	92.6	84.6	88.1	89.9
2500	88.6	81.9	87.4	81.8	82.3	88.9	81.5	86.1	87.4
3150	83.6	78.0	82.7	79.2	78.2	83.7	77.7	81.2	82.6
4000	79.0	73.6	78.1	74.3	73.6	78.8	73.2	75.9	77.0
5000	74.8	69.6	73.9	69.7	69.7	74.4	69.1	72.3	73.3
A-wtd	103.6	99.0	104.3	100.5	99.7	105.2	98.7	106.0	107.4

Table A8: OBSI levels for IR with the Old IGGA tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	85.7	83.9	83.5	84.4	85.8	85.1	83.3	89.2	90.2
500	86.5	85.4	85.0	87.5	89.5	87.4	86.5	91.1	93.0
630	90.3	90.3	90.7	92.8	92.7	92.0	90.8	95.1	98.2
800	96.0	92.9	97.0	96.0	94.3	97.8	93.5	99.7	102.7
1000	97.5	92.1	97.7	94.4	92.0	99.4	92.4	99.1	101.1
1250	96.2	89.6	96.7	91.8	90.1	97.9	90.7	97.8	98.5
1600	95.7	87.0	94.9	87.0	88.3	96.5	88.4	93.1	94.7
2000	93.8	84.8	92.5	83.3	86.3	94.4	85.9	89.4	91.5
2500	89.9	82.2	88.5	82.2	83.6	90.1	83.1	87.0	88.7
3150	84.5	78.4	83.4	79.8	79.3	84.6	79.1	81.9	84.0
4000	79.4	73.4	78.1	74.8	74.3	78.9	74.3	76.0	77.5
5000	75.2	69.6	73.8	70.3	70.3	74.3	70.1	72.5	73.8
A-wtd	103.6	98.6	103.7	100.8	99.9	105.1	99.3	105.1	107.3

Table A9: OBSI levels for UC PRC with the NC Rodeo tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	87.8	85.3	85.9	86.3	86.6	86.7	85.5	89.6	90.8
500	88.2	88.9	86.8	88.9	90.1	88.9	88.3	91.3	92.4
630	91.8	93.0	92.0	92.2	92.2	92.6	91.2	95.3	97.0
800	97.0	94.5	97.0	94.5	93.6	98.3	93.2	98.9	101.1
1000	97.9	93.0	96.7	93.6	91.2	98.9	91.8	97.9	99.5
1250	93.9	89.3	93.9	90.0	88.4	94.9	89.0	95.1	95.9
1600	95.2	86.7	92.9	85.5	86.6	95.1	86.7	90.6	91.9
2000	92.1	85.4	89.6	83.3	85.2	91.6	85.3	87.3	89.4
2500	88.4	82.2	85.8	80.9	81.8	87.5	81.7	84.8	86.8
3150	83.8	79.0	81.9	78.8	78.2	82.9	78.3	80.4	82.1
4000	81.0	75.9	78.6	75.5	74.9	79.5	75.1	76.9	78.6
5000	78.7	73.4	75.5	72.5	72.4	76.9	72.5	74.2	76.3
A-wtd	103.5	100.0	102.6	99.9	99.3	104.2	98.9	104.0	105.8

Table A10: OBSI levels for UC PRC with the IR SRTT #3 tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400	91.3	92.7	92.0	90.9	89.6	90.4	88.2	93.5	93.7
500	92.2	93.1	92.2	92.6	94.6	92.5	92.6	95.1	96.2
630	92.8	94.9	93.6	93.5	94.3	93.7	92.9	96.6	98.0
800	97.0	95.6	97.8	94.4	94.7	98.8	94.0	100.2	102.0
1000	97.6	93.4	97.0	93.0	91.5	99.4	91.8	98.7	100.0
1250	94.0	89.3	94.7	89.5	88.7	96.0	89.1	95.8	96.2
1600	93.6	84.6	92.3	83.6	84.6	94.9	84.6	89.7	90.9
2000	90.4	83.3	88.6	81.8	83.3	91.3	82.9	86.6	88.6
2500	87.1	80.9	85.1	80.5	80.8	87.6	80.4	84.5	86.1
3150	82.6	77.5	80.8	77.6	76.7	82.7	76.6	79.7	80.9
4000	79.7	74.6	77.8	74.6	73.4	79.2	73.5	76.3	76.9
5000	77.9	72.3	75.2	71.5	70.8	76.7	70.8	73.5	74.8
A-Wtd	103.2	100.4	103.0	99.5	99.6	104.7	98.9	104.5	105.8

Table A11: OBSI levels for IGGA with the Old IGGA tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400									
500	85.2	87.5	84.5	86.6	89.2	85.8	86.3	92.2	91.1
630	89.3	92.5	90.4	90.9	92.1	90.5	90.1	95.9	95.8
800	94.9	95.1	95.9	94.1	94.2	96.1	92.9	99.8	100.5
1000	97.6	93.2	96.5	93.2	92.1	98.6	92.3	99.6	100.1
1250	96.0	89.7	95.5	90.2	89.3	97.0	90.0	97.6	97.6
1600	95.5	87.3	93.6	86.5	87.5	95.5	88.1	93.5	94.2
2000	94.8	86.2	91.7	84.5	86.2	94.4	86.2	89.8	91.3
2500	90.3	83.7	87.2	82.5	83.2	89.6	82.9	86.6	87.9
3150	84.4	79.6	82.0	79.4	78.9	83.6	78.8	81.8	83.4
4000	79.2	74.2	76.5	74.1	73.7	77.9	73.8	75.7	76.9
5000	75.8	70.8	72.6	70.3	70.3	74.2	70.3	73.3	73.9
A-wtd	103.4	100.0	102.5	99.2	99.5	104.0	98.7	105.3	105.7

Table A12: OBSI levels for IGGA with the New IGGA tire on Loop 2, Oct. 11, 2012

Frequency	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
400									
500	86.5	88.2	85.0	87.4	89.1	87.1	87.0	92.3	92.3
630	90.3	93.0	90.3	91.6	91.9	91.6	90.7	96.3	96.8
800	95.8	94.6	96.0	94.2	93.3	97.4	92.9	100.1	101.0
1000	98.1	92.2	96.6	92.5	90.9	99.3	91.1	98.6	99.2
1250	94.4	88.3	94.3	89.2	88.2	96.0	88.7	95.4	95.5
1600	94.2	85.3	91.7	83.8	86.0	94.9	86.1	90.1	91.4
2000	92.6	84.3	89.6	81.7	84.5	92.8	84.7	87.8	89.2
2500	88.5	81.6	85.7	80.1	81.3	88.5	81.3	84.9	86.1
3150	82.6	77.6	80.4	77.5	77.2	82.6	77.2	79.8	81.2
4000	78.5	73.4	76.0	73.0	72.7	77.8	72.9	74.7	75.8
5000	75.0	70.0	72.1	69.0	69.2	73.9	69.3	71.7	72.7
A-wtd	103.0	99.4	101.9	98.9	98.6	104.1	98.2	104.6	105.3