PCC SURFACE CHARACTERISTICS
MNROAD STUDIES
DATA ANALYSIS

Year 2 Annual Report

Task 4: Submit Annual Reports

DRAFT

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This is the second of three planned annual reports describing the performance of various methods of diamond grinding on Cells 7, 8, 9 and 71 at the MnROAD pavement testing facility near Albertville, Minnesota. The purpose of this study is to analyze the long term performance of different diamond grinding patterns ground on Portland Cement Concrete Pavement. Cells 7 and 9 are Next Generation Concrete Surface grinds (NGCS) and Cell 8 is a conventionally ground surface. Cells 7 and 8 were ground in October 2007, Cell 9 was ground in October 2008, and Cell 71 is another iteration of the ultimate grind, which was ground in May 2010. Cell 12 is used as a control section, since it has not been ground, and has its original transverse tined surface texture as it was originally constructed in 1992.

The data collection for this project is conducted by MnDOT, with data analysis and reporting conducted by the research staff at the Center for Transportation Research and Implementation at Minnesota State University, Mankato. For this second annual report, data is included through the summer of 2011. This section describes the data that has been collected and the dates and times of its collection, since the beginning of the project.

In addition, a summary of the study on the effects of air temperature on OBSI noise levels is discussed in this annual report, along with a preliminary implementation of the results. A final adjustment to the noise data based on the correction factor developed will be presented in the third annual report.

The information in Table 1 summarizes the test data available to the research project, conducted by MnDOT since the three test sections were ground.

Table 1. Dates and Types of Testing Conducted.

Testing Date	Characteristics Measured			
	Noise	Friction	Texture	Ride
17 Aug 2007	X			
8-10 Sep 2007	X			X
15 Oct 2007			X	
22-23 Oct 2007	X		X	X
21 Nov 2007		X		X
28 Mar 2008				X
2 Apr 2008	X			
28 May 2008		X		
25 Oct 2008			X	
31 Oct 2008		X		
2 Nov 2008			X	
19-20 Nov 2008	X			X
5 Dec 2008	X			
15-16 Mar 2009	X		X	
27 April 2009				X
16 Jun 2009		X		
21 Jul 2009	X			
15 Sep 2009	X			
28 Oct 2009				X
17 Nov 2009	X			
8 Mar 2010	X			X
8 Apr 2010				X
1 Jun 2010			X	
28 Jul 2010	X			
17 Sep 2010	X			
17-20 Sep 2010	X	X		
12 Oct 2010				X
20 Oct 2010			X	
17 Nov 2010	X			
15 Mar 2011	X			
14 Apr 2011		X		
24-28 Jun 2011	X		X	

Noise

Noise testing reported here was conducted using the On-Board Sound Intensity (OBSI) method. This method uses two microphones to collect sound data from both the leading edge and the trailing edge of the tire, as shown in Figure 1. A standardized tire referred to as the Standard Reference Test Tire is also used, as specified by ASTM F 2493.

After the initial grinding on each cell, there was a significant reduction in noise from the innovative grind compared to the conventional grind. In fact, after the grinding was performed in October 2007 on Cells 7 and 8, there was a 4.5 dB difference between the innovative grind on Cell 7 and the conventional grind on Cell 8.

Figure 1. On-Board Sound Intensity Test Setup.

Cell 9 was ground in October of 2008, approximately 1 year after Cells 7 and 8. Cell 71 was ground about 1½ years after Cell 9. Figures 5 and 8 show the OBSI noise level measurements for the driving lane and passing lane of all four of these cells, respectively, tested on the dates provided in Table 1.

Noise – Temperature Correlation

It is important to note that these tests were performed at different times of the year, and at various times during the day. The temperature of the air, the road surface and the tire are different at each different testing period. Since the air temperature can have an effect on the noise measured by the OBSI equipment, it is important for the noise data to be adjusted for these differences. The next section describes a program of data collection to develop a preliminary temperature correction function for the OBSI data. This testing program involved two full-day testing sessions where OBSI testing was conducted throughout the day at different air temperatures to determine the effect of air temperature on pavement noise. The testing was conducted on 18 April and 28 June 2011. The ambient temperature ranged from 33 to 50 °F on 18 April 2011 and from 54 to 77 °F on 28 June 2011. This provided a wide range of temperatures from which to develop a correction factor.

The testing was conducted on the entire MnROAD mainline including all of the cells in service at that time. The correction factors developed here are for the diamond ground concrete surfaces in Cells 7, 8, 9, 71 and the transverse-tined control cell (Cell 12), and using the following parameters.

- Ambient temperatures from 30 to 77 °F
- Uniroyal TigerPaw SRTT
- Vehicle speed of 60 mph
- Two runs per hour, every hour, for 13 hours each test date

The data shown in Figure 2 indicates the relationship between air temperature and measured OBSI noise on Cell 8. The same type of information can be seen in Figure 3, which shows the relationship between noise and both air and pavement temperature. Since these figures indicate similar relationships, since air and pavement temperature are closely correlated, and since there is a well established understanding of the physical nature of sound intensity and the temperature and density of air, the ambient air temperature will be used throughout this report to establish the preliminary correction factor for OBSI readings at different temperatures.

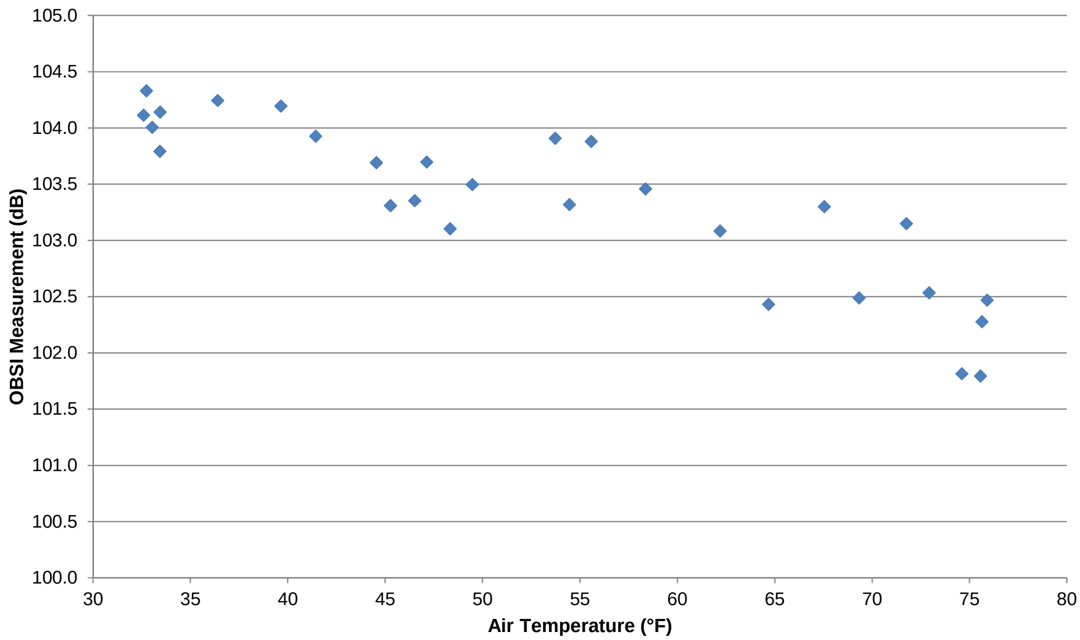

Figure 2. Noise–Temperature Relationship (Cell 8).

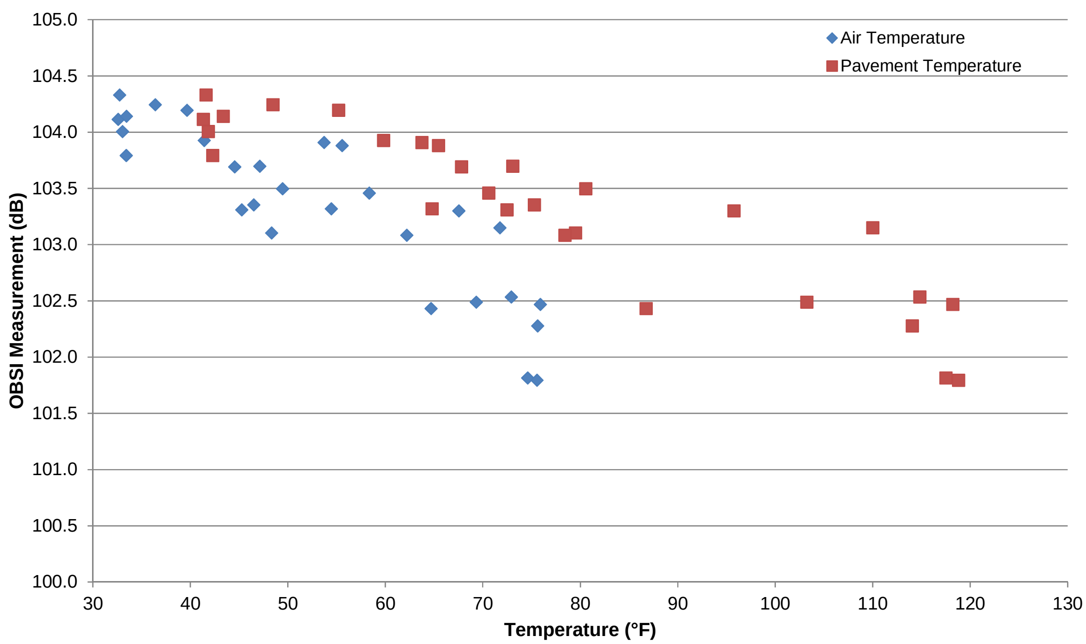

Figure 3. Noise Relationship to Air and Pavement Temperature (Cell 8).

For a correction factor to be established, a reference temperature must be selected as a base which all other results are corrected. In other studies of this nature, a standard reference temperature of 68 °F (20 °C) has been used. The general form of the correction function is most often a variation of the following.

$L_c = L_m + c \cdot (T_m - T_{ref})$ Equation 1

where:

L_c = corrected sound level, dB
L_m = measured sound level, dB
T_m = measured air temperature (°F or °C)
T_{ref} = reference air temperature (°F or °C)
c = correction coefficient (dB/°F or dB/°C).

Results from other studies in Europe and the United States include the following. Many existing analyses compare temperature to pavement-tire noise using the Statistical Pass-By method rather than the OBSI testing that was done for this project.

- The Danish Road Institute correction for Statistical Pass-By measurements (1)

  $T_{corr;P} = 0.05(T_{measured} - 20)$ Passenger cars
  $T_{corr;H} = 0.03(T_{measured} - 20)$ Heavy Vehicles

  The report indicates that these are for the statistical pass-by rather than on-board sound intensity measurements.

- Sandberg and Ejsmont (2) suggested coefficients for temperature correction of sound measurements using a similar form (in terms of dB/°C) and developed a table of coefficients for various types of pavement surface, textures, and aggregate gradation. Again, these are not suggested for OBSI measurements.

- A study was performed in 2008 in Florida by Donavan and Lodico (3) using OBSI measurements and a range of air temperatures from 86 to 104 °F. Depending on the tire used and the surface type tested, the correction ranged from -0.024 to -0.100 dB/°C.

- Smit and Waller (5) conducted a study on temperature effects using close-proximity (CPX) testing and found no statistically-significant correlation between air temperature and noise measurements. This is primarily because the standard deviation in some of the noise data is as large as the correction coefficient itself. They found further evidence that the temperature may affect some of the frequencies measured by the CPX equipment more than others. The effect of temperature on sound intensities at various frequencies will be investigated further and reported in the third annual report for this project.

Other reported results are similar to those described above, where testing and correlations are based on noise testing different that what was done at the MnROAD site.

Figure 4 shows the correction of noise data for Cell 8 (conventional). This figure indicates the original data as measured, and the corrected data using the derived correction factor, or coefficient ‘c’ in Equation 1. The slope of the trend line for the Measured data in the figure is -0.042. When corrected, the slope is zero, and the point where the two trend lines intersect is the base temperature of 68 °F. Using this method, correction coefficients for each of the four cells were developed, and are provided in Table 2.

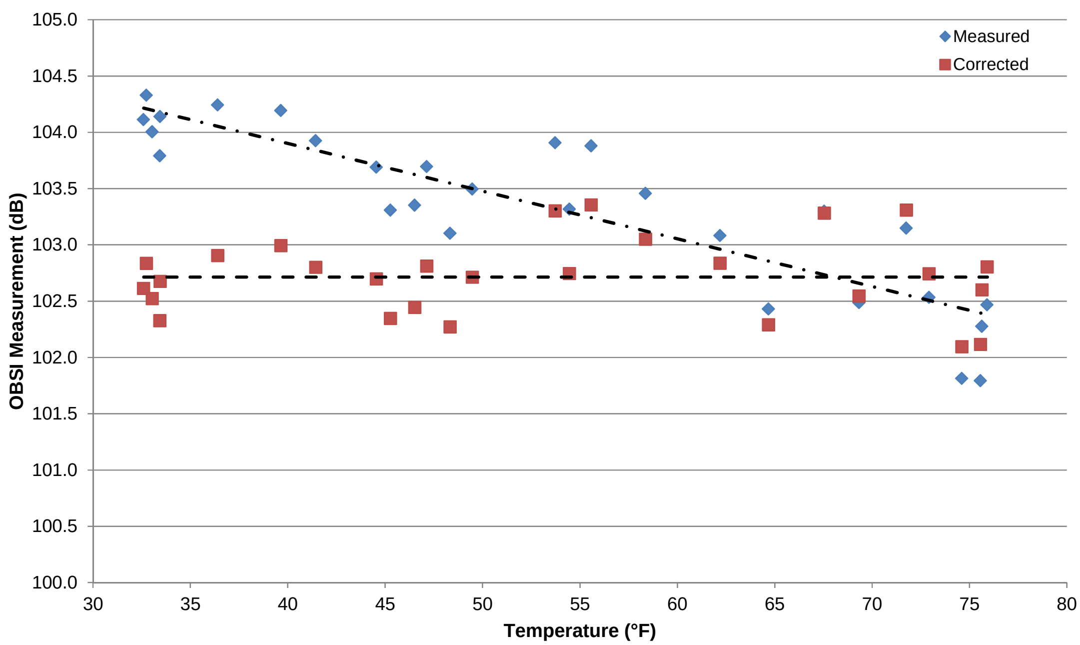

Figure 4. Measured and Corrected OBSI Values, Cell 8.

Table 2. Temperature Correction Coefficient for Different Grinds.

MnROAD Cell	**Noise-Temperature Coefficient, dB/°F (dB/°C)**
12 (Control)	-0.019 (-0.034)
8 (Conventional)	-0.042 (-0.076)
7 (Innovative)	-0.015 (-0.027)
9 (Ultimate)	-0.019 (-0.034)
71 (New Ultimate)	-0.0095 (-0.017)

Using the correction factors in Table 2, the noise data presented in Annual Report #1 (and updated since that date) are adjusted for further use in this current annual report, observing trends in the data. For example, the data shown in Figures 5 and 6 present the OBSI measurements for the grinding cells and for the control cell. Figure 5 shows the unadjusted data for each of these cells. It is clear that there are seasonal effects where the measured sound intensity increases and decreases on approximately an annual basis, with the general level increasing in the last two years of data. Figure 6 shows the same noise information as the previous figure, but with the temperature correction applied. As an example, Figure 7 shows the Cell 8 driving lane with and without temperature correction so that the effect can be seen more readily.

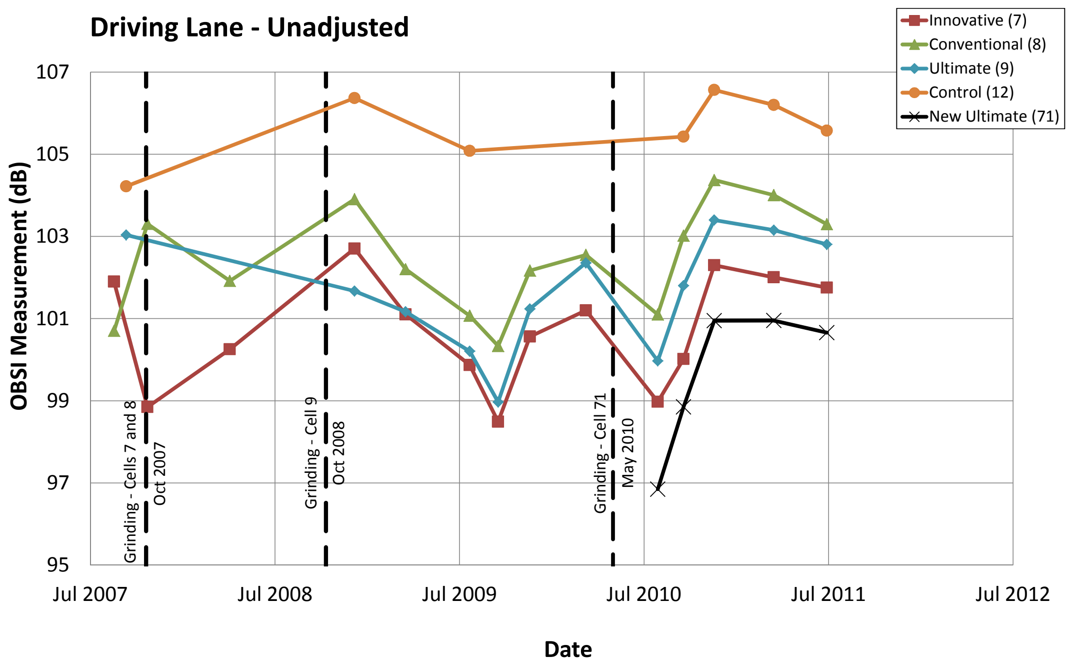

Figure 5. OBSI Measurements – Driving Lane – Unadjusted.

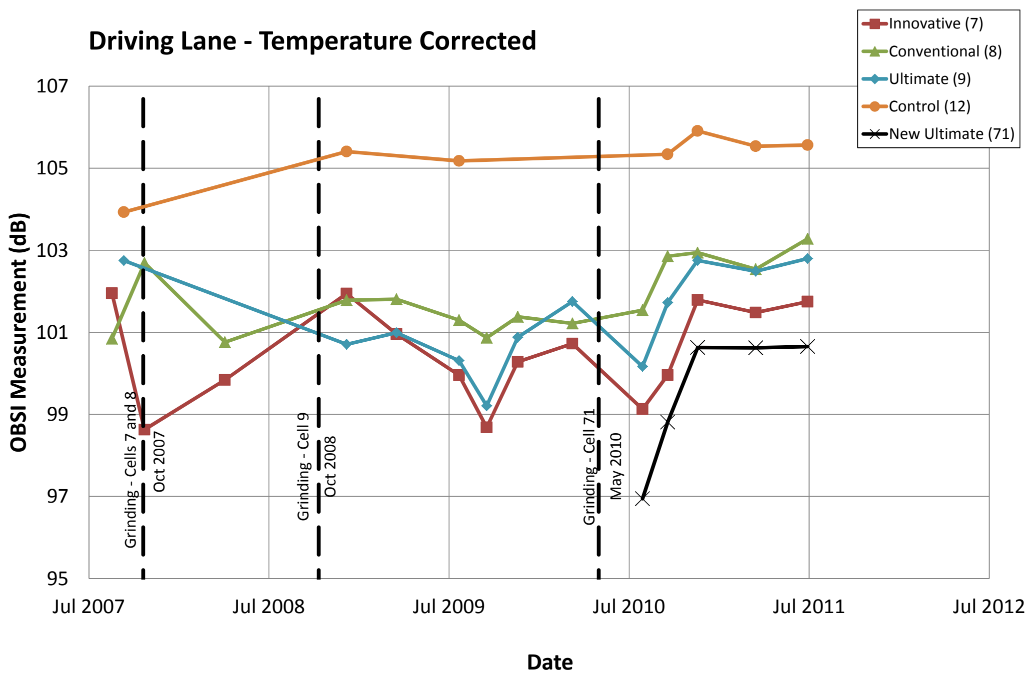

Figure 6. OBSI Measurements – Driving Lane – Preliminary Temperature Correction.

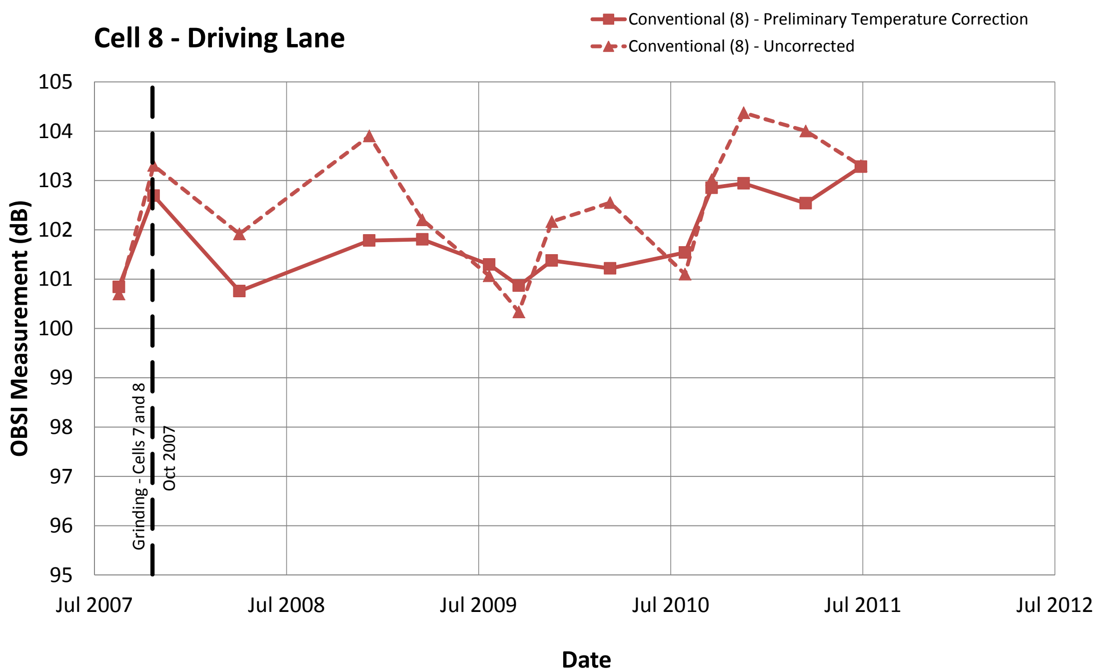

Figure 7. OBSI – Cell 8 Driving Lane, with and without Preliminary Temperature Correction.

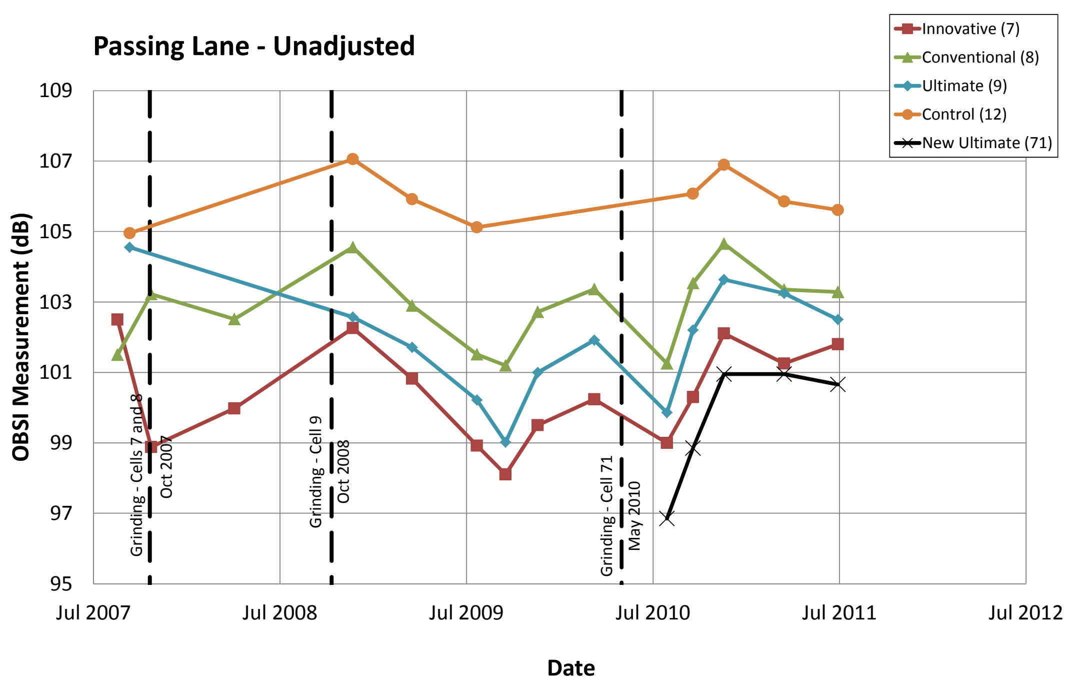

Figure 8. OBSI Measurements – Passing Lane.

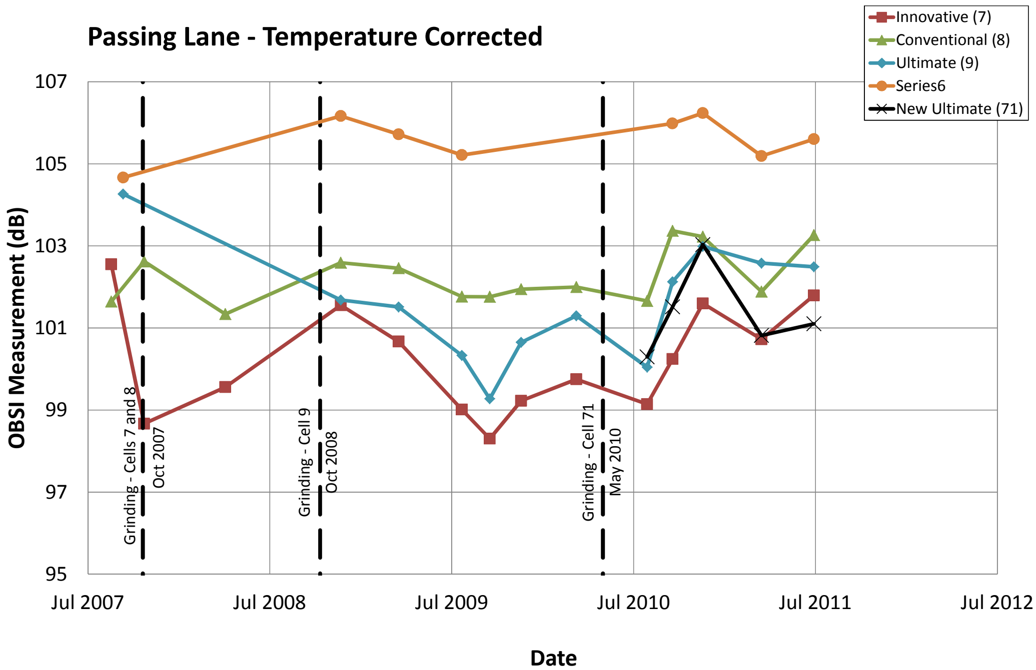

Figure 9. OBSI Measurements – Passing Lane – Preliminary Temperature Correction

No OBSI testing was conducted immediately prior to the grinding of Cell 9, so the immediate effects on noise levels are not known. The differences between OBSI measurements on different cells are shown in Figures 10 and 11 for the driving and passing lanes, respectively. In the figures below, the legend indicates the comparison made. For example, when comparing the conventional to the innovative grind, the "Conventional – Innovative" notation indicates that the conventional grind is louder by the ordinate of the line at the particular time. Also in the comparisons between cells with measurements taken on the same day, the temperature correction factors are not needed.

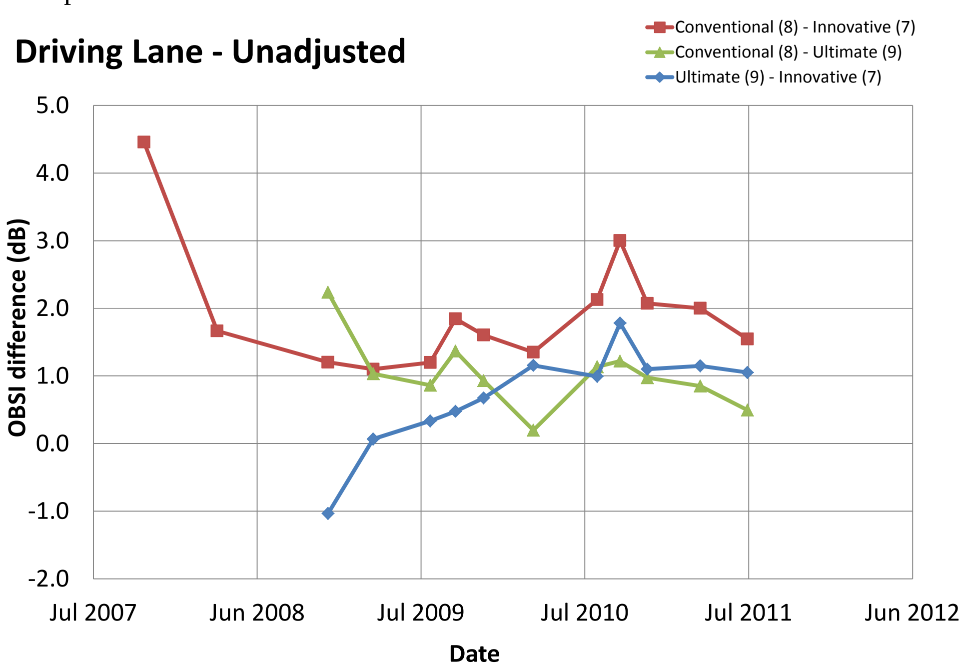

Figure 10. Difference in OBSI Measurements – Driving Lane.

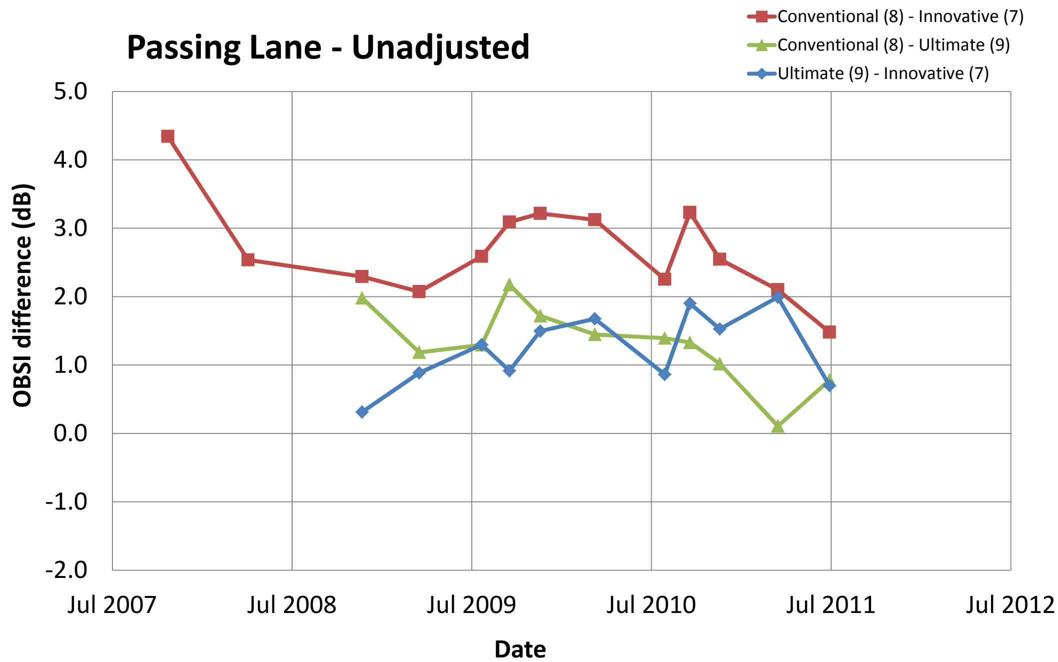

Figure 11. Difference in OBSI Measurements – Passing Lane.

Initially there seemed to be a significant difference between the conventional and innovative grinds (meaning that the conventional grind was up to 4 dB greater than the innovative grind). In a short time, however, and for the next few measurements, the difference was just above 1 dB. Measurements over time in the comparison of these two cells seem to show the differences within a range of about 1 to 3 dB in the driving lane, and between 2 and 3 dB in the passing lane.

Another comparison of noise data should be made between the grinding cells and the control cell (Cell 12). Cell 12 is a useful comparison since it has not shown much change in OBSI measurements over the four years of data collection during this project, as seen in Figures 5 through 9. The comparisons in Figure 12 reflect the variations in the measured data from the previous figures. As described above, since all of the measurements for each date were taken on the same date, and in fact within seconds of each other, the temperature correction is not necessary. Thus, it can be seen in Figure 12 that after the initial year or two after grinding the difference in noise levels between each of them and the control cell has been decreasing. Since the Cell 12 measurement has not changed significantly over this period of time, the conclusion may be drawn that the grinding cells have either increased in noise or remained approximately the same, relative to the control cell, since July 2009.

One other important method of comparison is to observe the differences in noise by the time since the grinding was conducted on each cell. As described in the previous annual report, one fortunate coincidence is that the grinding on Cell 9 occurred almost exactly one year after the grinding on Cells 7 and 8. Also, there are three testing dates subsequent to Cell 9 grinding that fall one year after testing within a few days of the same age on Cells 7 and 8. The comparison of noise measurements based on time since grinding in the driving and passing lanes are shown in Figures 13 and 14, respectively. In this case, however, it is important to apply the temperature corrections, since the measurements were not taken on the same dates, or more importantly, at the same temperatures.

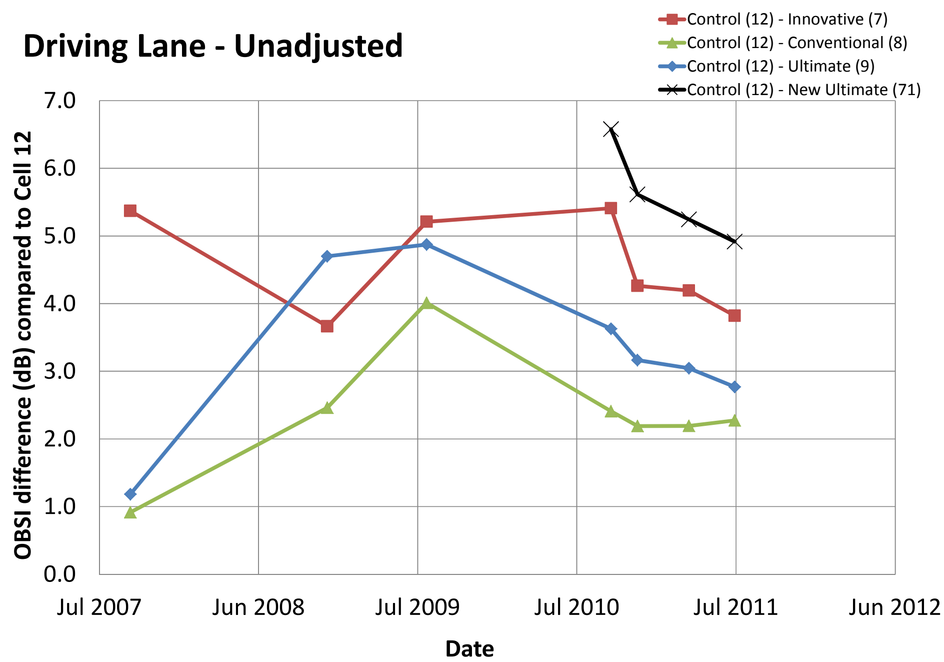

Figure 12. Difference in OBSI Measurements – Driving Lane, Grinding Cells Compared to Control.

An observation that is readily noticed in the driving lane figure is that the innovative and ultimate grinds started at about 5 dB quieter than the control cell, whereas the conventional grind started at just over 1 dB quieter. This may be an effect of the variation in the noise measurement, however, since at about one year after grinding all four cells were about 3.5 to 5.0 dB quieter than the control section. After about two years post-grind, however, the conventional and ultimate grinds seem to remain about 2.5 to 3.0 dB quieter than the control. Similarly, the innovative grind seems to have remained at about 4.0 dB quieter than the control since about three years post-grind. There is still not adequate data to make specific determinations about these trends, however.

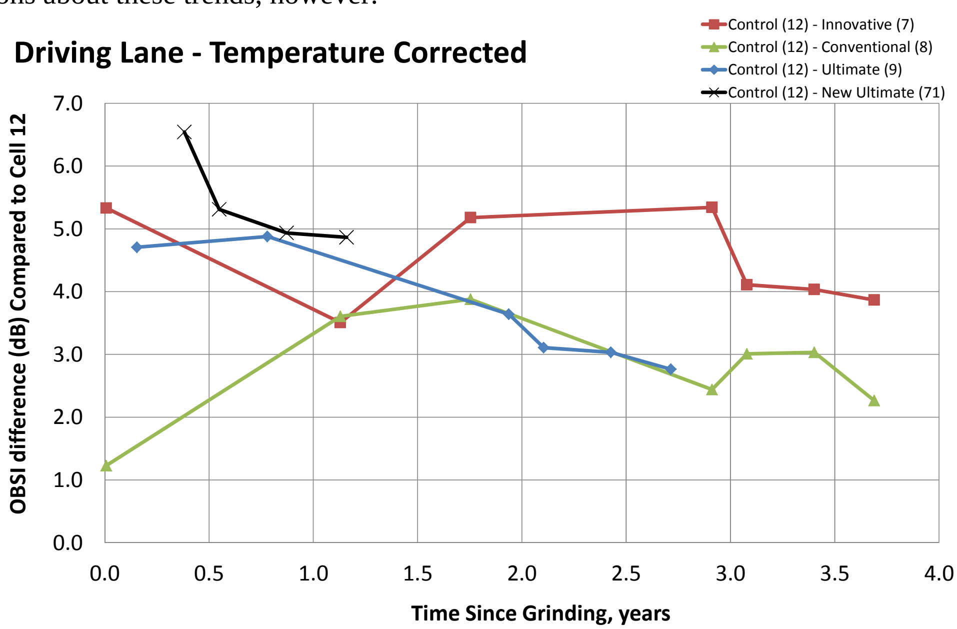

Figure 13. Difference in OBSI Measurements by Time Since Grinding – Driving Lane.

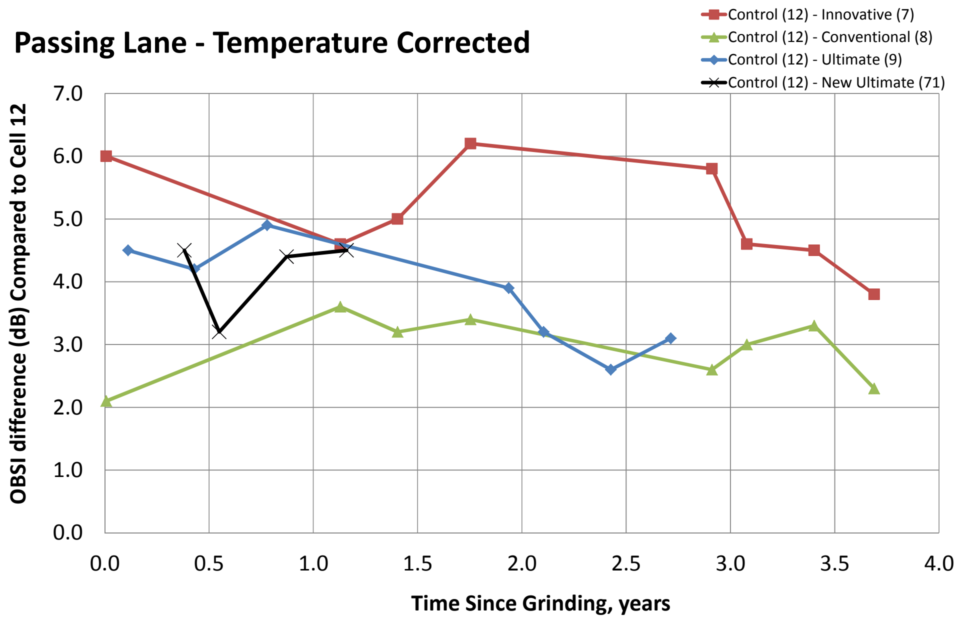

Figure 14. Difference in OBSI Measurements by Time Since Grinding – Passing Lane.

The trend analysis of OBSI measurements over time will be conducted and presented in the third annual report. This will be conducted using a Mann-Kendall test for identifying trends. This test requires a minimum of 10 data points to provide meaningful results. In each of the 2007 and 2008 grinding cells there are at least ten data points. The data will be tested using both the unadjusted and the temperature corrected values and conclusions regarding the results will be discussed.

Friction

The purpose of friction testing is to compare how the performance of the surface grinding methods maintain their friction characteristics over time. It is important to evaluate each point and adjust for climatic conditions such as surface temperature and others when comparing individual test results. After the initial pavement grinding, the friction number was higher for the conventional grind than for the innovative grind using both a ribbed and smooth tire. The ultimate grind was performed on Cell 9 approximately one year after the conventional and innovative grind. The results of the friction testing in the driving and passing lanes (using the ribbed tire) are shown in Figures 15 through 18. The same results for the smooth tire testing are shown in Figures 19 through 22. Only one additional set of friction testing was conducted since the last annual report, thus the many of the conclusions will remain the same.

After Cells 7 and 8 were ground, it appears that the friction on Cell 8 (conventional) increased while the friction of Cell 7 (conventional) decreased between the first and second test dates. In the initial period after grinding, the fins remaining on the conventional grind break down and the overall friction decreases, whereas for the innovative grind, these fins are not left behind in the grinding process. The conventional surface outperformed the Innovative grind by a friction number of almost 10, initially, and increased to a difference of about 12 by the time of the second test in May 2008.

After its high point measured at about seven or eight months after grinding, the friction on the conventional grind decreased at approximately a constant rate for about a year, and then has remained mostly constant at a friction number of 50 since July 2009. The innovative grind has had a relatively constant friction number of about 45 since it was ground. The ultimate grind surface has similarly remained at about 45 to 50 since grinding.

At this point, only a few friction results have been obtained for the control cell (Cell 12). It is assumed that more data exist, and these will be obtained prior to the third annual report. For the driving lane and ribbed tire, the friction of the control cell is very similar to the other cells – with friction numbers around 45 to 50. In the passing lane, the control and conventional grind are slightly higher in friction number, but only by about 5 or 6 points. The innovative and conventional grinds are almost identical, at about FN of 49.

With the smooth tire, the control cell shows a significantly lower FN than all of the grinding cells (in the driving lane) and only slightly less in the passing lane. This seems reasonable, since the driving lane will have had much more traffic than the passing lane over time.

The friction performance can be compared perhaps more appropriately by comparing the surfaces with respect to the elapsed time since they were ground, instead of by date. Figures 17 and 18 are made up of the same friction data as Figures 15 and 16, but are shown in terms of the age, or time since grinding. Essentially, the ultimate grind data are offset so that it can be directly compared to the others which were ground one year earlier.

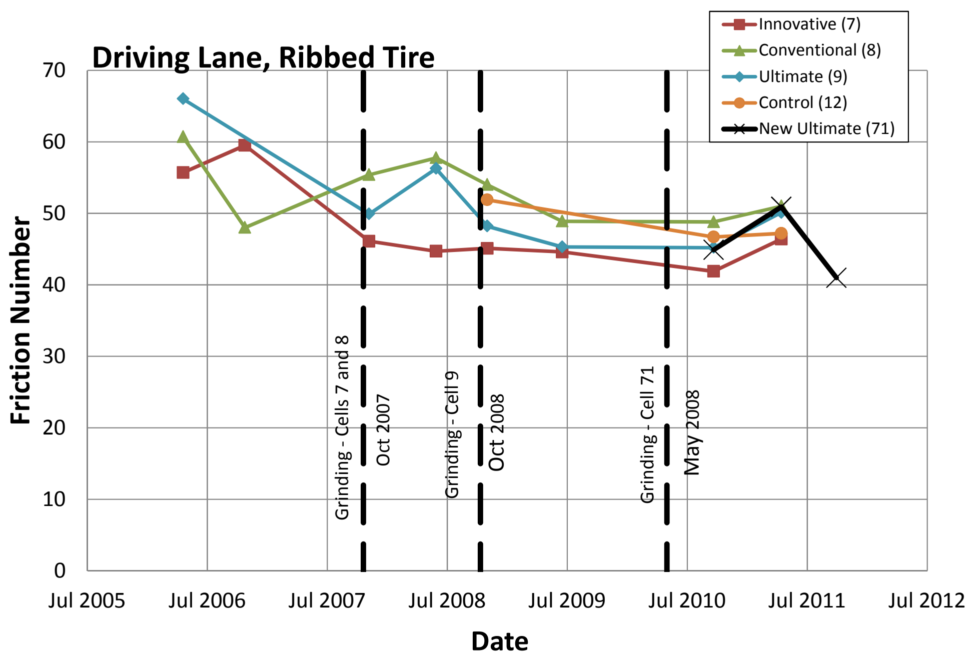

Figure 15. Friction Test – Driving Lane, Ribbed Tire by Test Date.

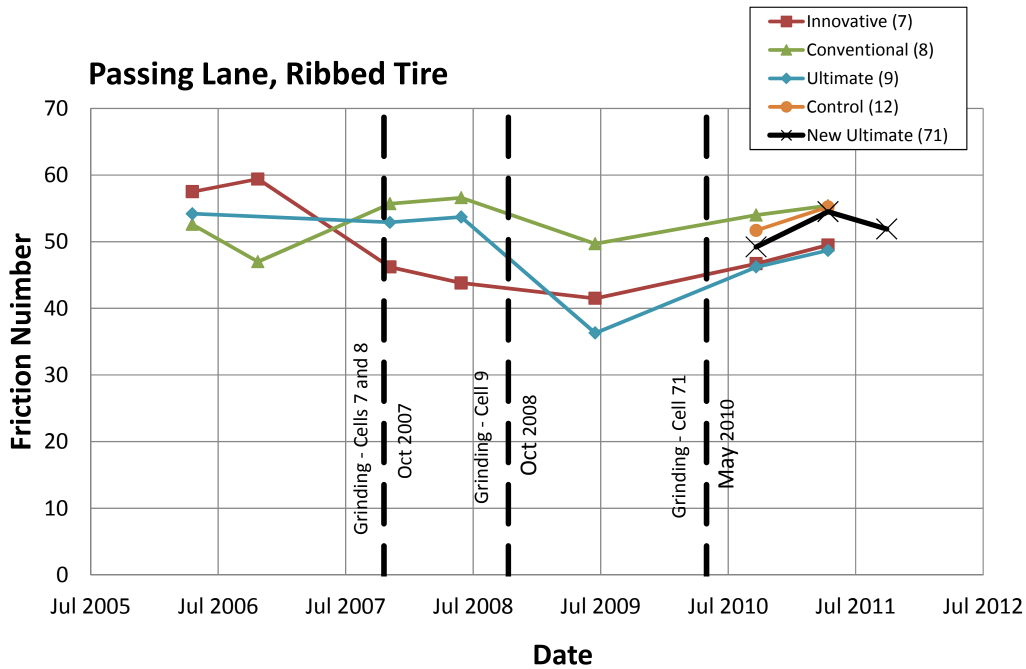

Figure 16. Friction Test – Passing Lane, Ribbed Tire by Test Date.

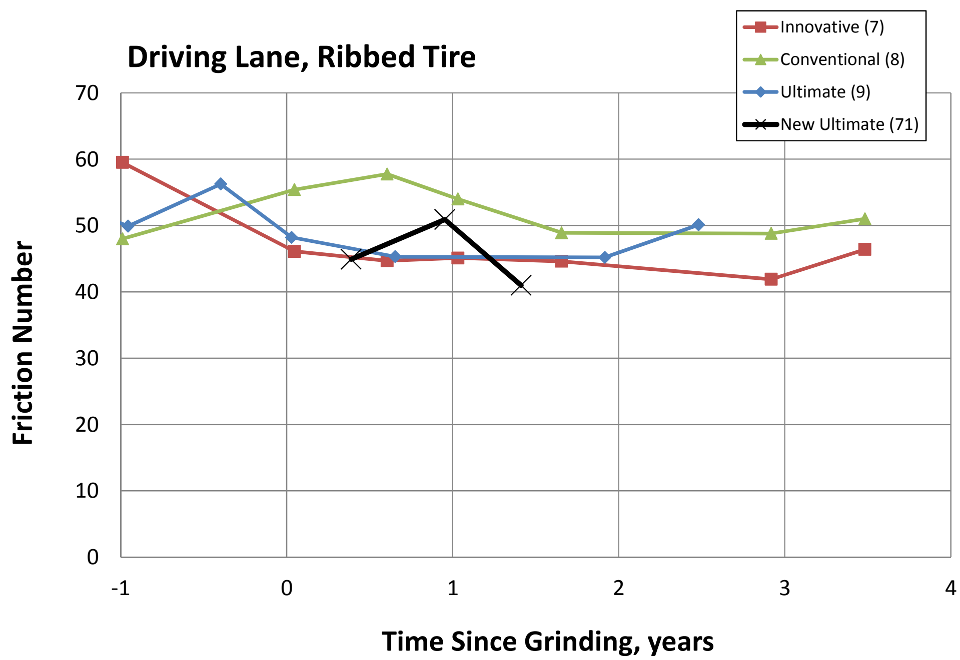

Figure 17. Friction – Driving Lane, Ribbed Tire by Time Since Grinding.

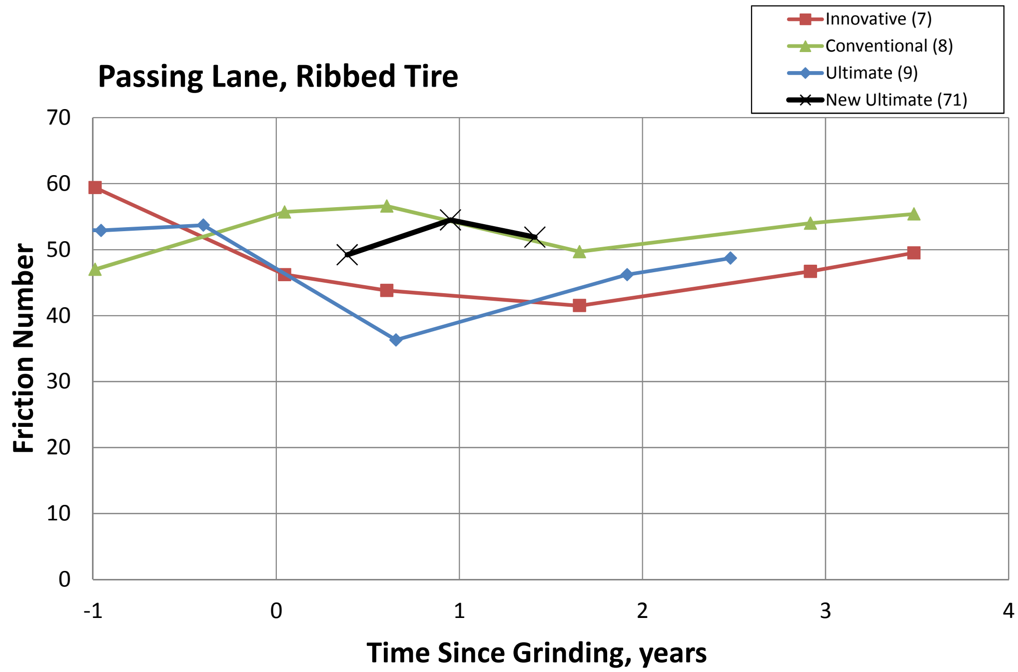

Figure 18. Friction – Passing Lane, Ribbed Tire by Time Since Grinding.

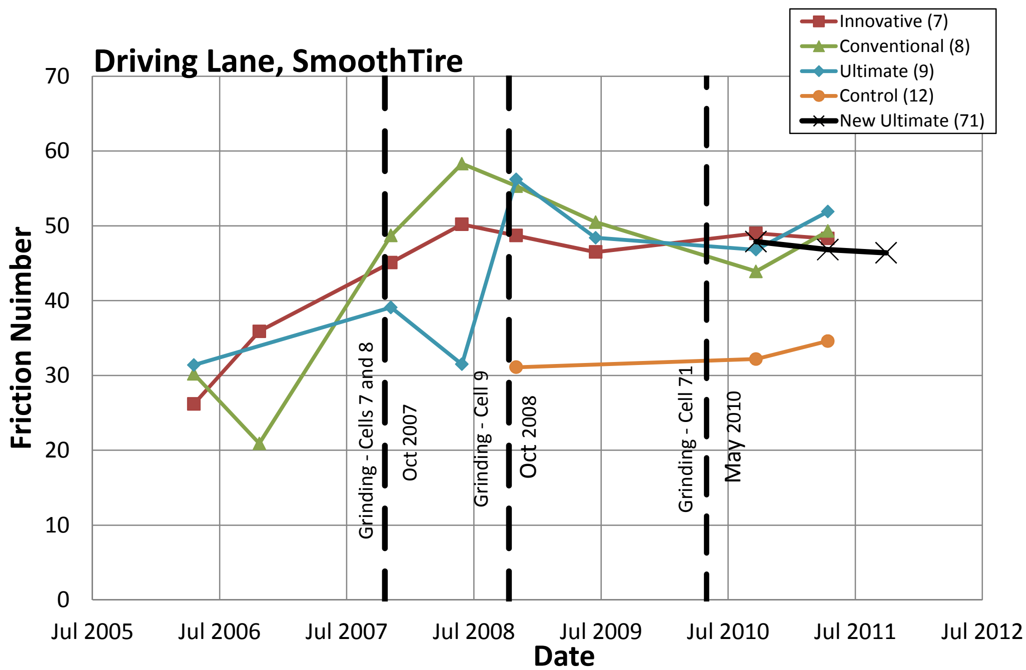

Figure 19. Friction Test – Driving Lane, Smooth Tire by Test Date.

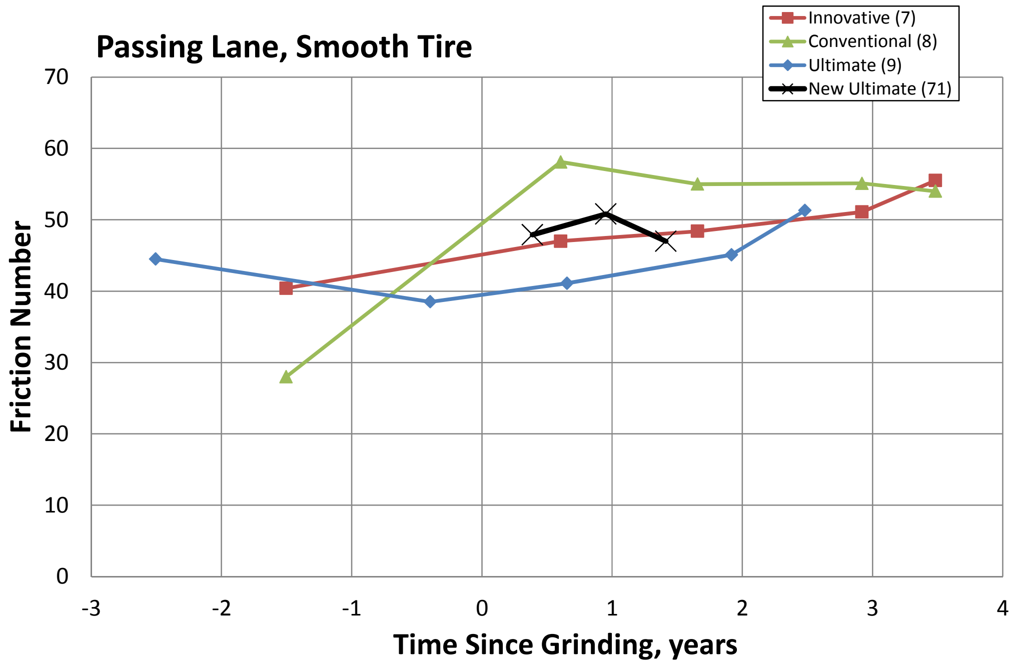

Figure 20. Friction Test – Passing Lane, Smooth Tire by Test Date.

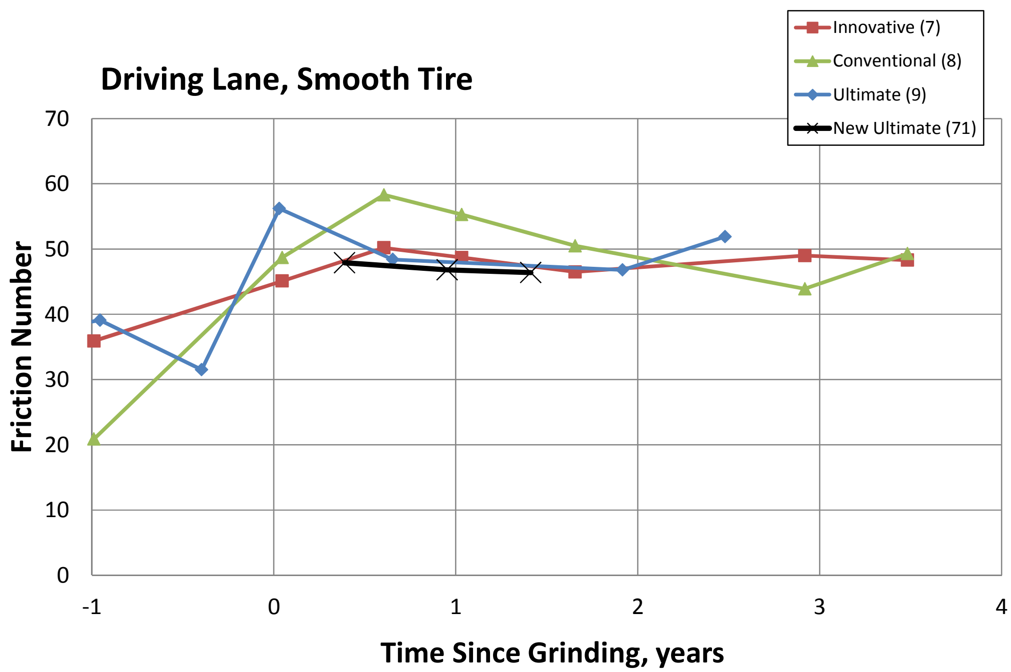

Figure 21. Friction Test – Driving Lane, Smooth Tire by Time Since Grinding.

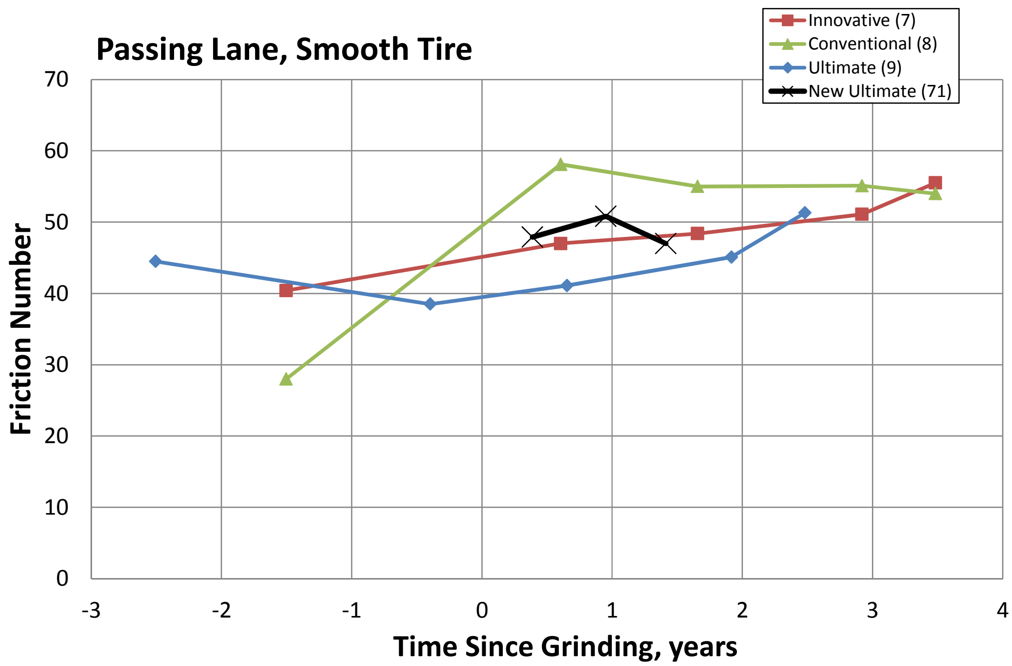

Figure 22. Friction Test – Passing Lane, Smooth Tire by Time Since Grinding.

The results of these tests are not entirely conclusive, but a few points of interest can be noted. The first is that the friction characteristics for the innovative and ultimate grind surfaces were less than that of the conventional surface using the ribbed tire, and for some of the tests using the smooth tire. The intent of the ultimate grind surface is to increase the friction characteristics of the innovative grind surface. The conventional grind has consistently demonstrated a friction number almost FN 5.0 higher than the innovative surface when considering the ribbed tire in both lanes, at the same age.

Texture

New data for mean texture depth is not available since the last annual report, except for the additional data for Cell 71. Thus, new information is not included in this section. For continuity, however, the previous discussion is maintained in this annual report, with minor corrections and clarifications.

The average texture depth was testing using the ASTM E 965 method. After the initial grinding of Cells 7 and 8 the test shows that the average texture depth was much greater for the conventionally ground pavement. However, because the conventional grind has narrower fins, they are more easily broken and worn down. This causes the average texture depth from Cell 8 to deteriorate more quickly than for Cell 7, although both seem to arrive at about the same texture measurement within about 2.5 years. The results of the texture testing are shown in Figures 23 and 24.

Immediately after Cells 7 and 8 were ground in October 2007, the difference in the mean texture depth between the two cells was 0.57 mm on the driving lane. The difference in texture depth between the two cells from the most recent test (June 2010) was found to be only 0.02 mm.

As mentioned previously, the Ultimate grind was performed on Cell 9 one year after the grinding of Cells 7 and 8, and the new ultimate grind on Cell 71 was conducted 18 months after that. As can be seen in Figure 23, the ultimate grind begins with a higher average texture depth than both the innovative and conventional grinds, and decreases more slowly than the conventional grind, to this point. The new iteration of the ultimate grind does not display texture depth any different than the other two types of grind.

The innovative and conventional grinds show the increase in texture depth due to the grinding (both were at about 0.45 mm). In the passing lane of the ultimate grind, where fewer vehicles have traveled, the MTD is greater by almost the same amount at each measurement, even though the overall measurements have decreased over time. With the other types of grind, the difference between the passing and driving lanes is more variable – in some cases they are at about the same measurement.

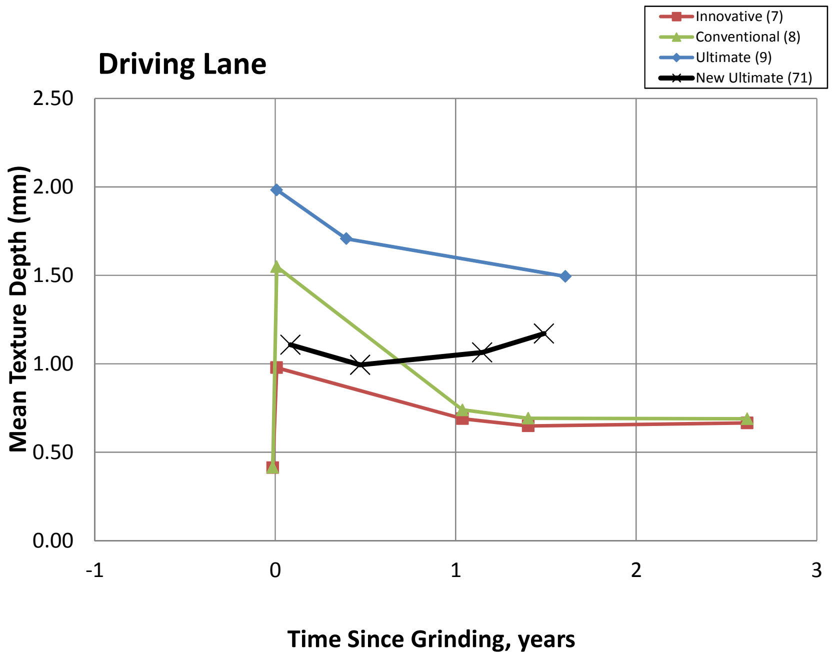

Figure 23. Average Texture Depth – Driving Lane.

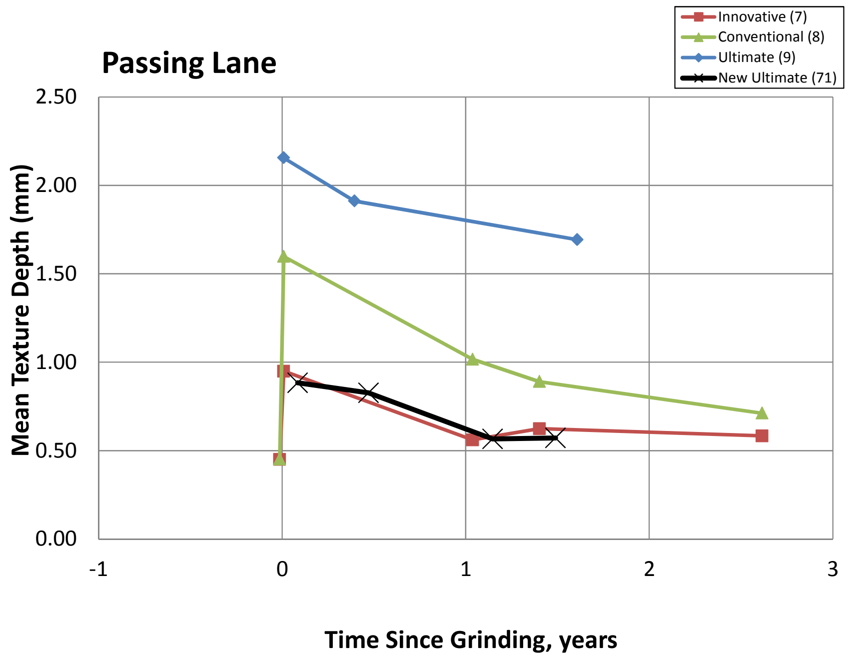

Figure 24. Average Texture Depth – Passing Lane.

Ride Quality

Ride quality is measured using the AMES LISA Light weight profiling device. The International Roughness Index (IRI) was computed using the ProVAL software developed by the Federal Highway Administration. Although ride quality data is collected frequently at the MN Road Facility, additional data beyond October 2010 has not been obtained at this time. As with the other surface characteristics, the ride quality data is presented in two ways – by date and by time since grinding. In general, the ride improved due to the grinding, on the innovative and conventional grind cells. They each decreased by about 30 – 40 in/mi. While all of this improvement is not necessarily due to the grinding, much of it might be attributed since the time between the measurements was only about six weeks, and it is unlikely that other factors contributed to a decrease in roughness.

As can be seen in Figures 25 through 28, the IRI for the two grinding cells completed in 2007 improved dramatically at the next measurement immediately following the grinding. The data for the ultimate grind (Cell 9) seemed reasonable *prior* to grinding, but the first measurement after grinding reported an IRI of over 200 in/mi, where only six months earlier it had been about 85 in/mi. In fact, the measurement at the time of the grinding of Cells 7 and 8 (one year prior to its own grinding) Cell 9 was profiled and reported only 48 in/mi. Such a dramatic increase, spanning the time of the grinding, seems unreasonable, and thus the data for this cell were removed from the analysis.

Another seeming anomaly is the spike in IRI on the control cell (Cell 12) in March 2010. Disregarding that data point, the remainder of the IRI data for Cells 7, 8 and 12 seem reasonable, and commensurate with the data on the passing lane.

There are other reasons for not including much more information on ride at this point, primarily that additional information needs to be collected about the analyses conducted on the data at different times since grinding. For example, the data filters applied to the pavement profiles need to be the same for a real comparison to be of any value.

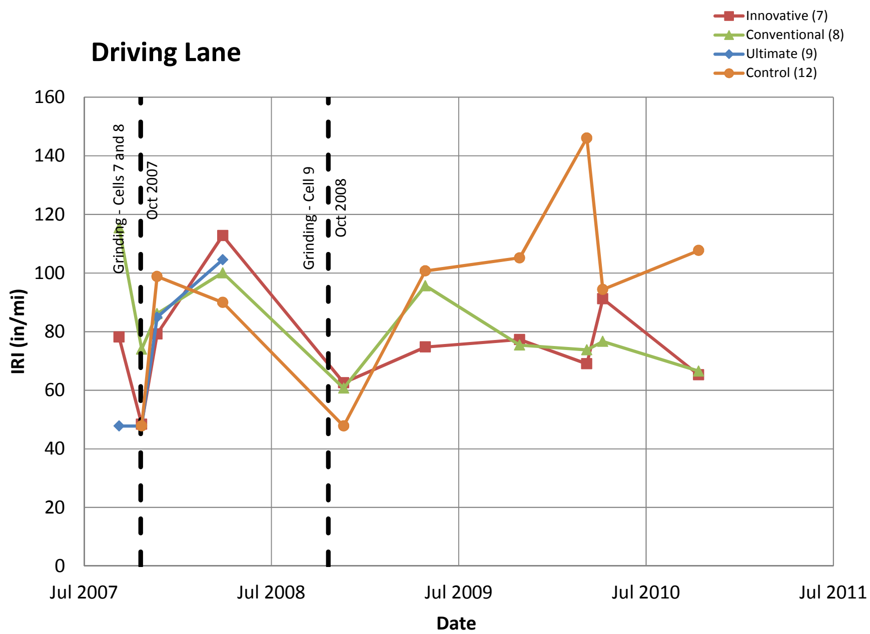

Figure 25. Ride Quality - Driving Lane by Test Date.

When comparing the IRI data plotted by time since grinding, it is apparent that Cells 7 and 8 (the innovative and conventional grind cells, respectively) have IRI values between about 80 in/mi, and that the measurements remain somewhat consistent over several years.

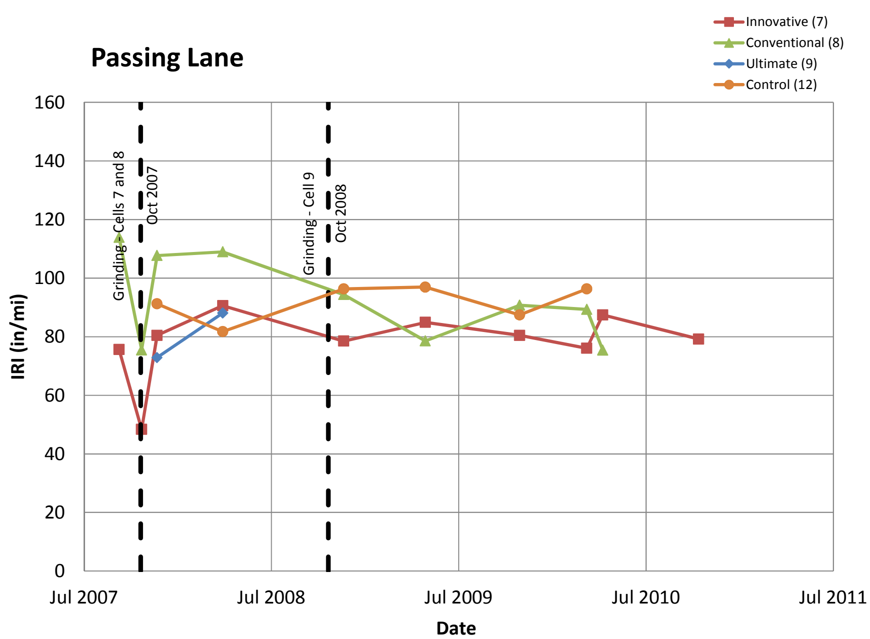

Figure 26. Ride Quality – Passing Lane by Test Date.

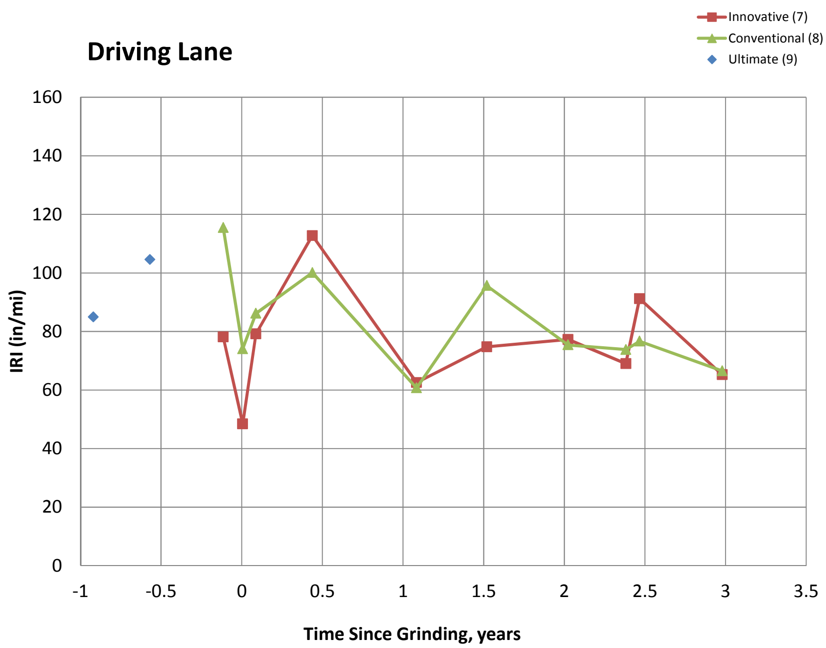

Figure 27. Ride Quality – Driving Lane by Time Since Grinding.

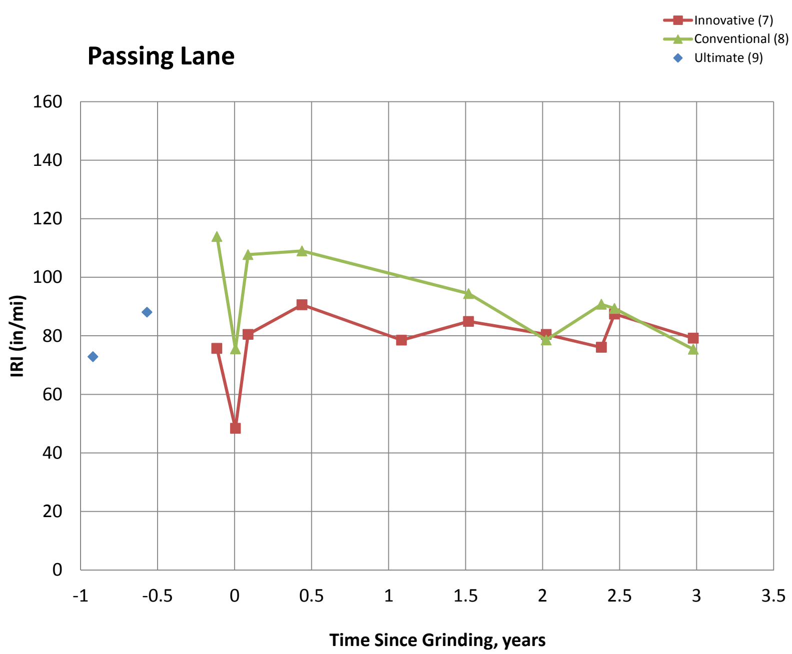

Figure 28. Ride Quality – Passing Lane by Time Since Grinding.

References

1. Optimized thin layers – urban roads – the Kastrupvej experiment. Danish Road Institute/Road Directorate, Technical Note 66, 2008. See: www.roadinstitute.dk

2. Sandberg and Ejsmont Semi-generic temperature corrections for tyre/road noise. Ulf Sandberg. Proceedings Inter.Noise conference 2004 in Prague.

3. Effect of Test Parameters on OBSI Measurements. Paul R. Donavan, Illingworth & Rodkin, Inc and Dana M. Lodico, ICF Jones & Stokes. Presentation at TRB ADC40 Summer Meeting Key West, Florida. July 2008. See http://www.adc40.org/summer2008/LodicoTRB08.pdf

4. Further analysis of the Sperenberg data. Towards a better understanding of the process influencing tyre/road noise. Report M+P.MVM.99.3.1 revision 1. 30th November 2001. M+P Consulting Engineers, the Netherlands.

5. Smit and Waller (TRB 2008, paper 08-0389).

APPENDIX A – TEST DATA SUMMARY

OBSI Testing

Table 3. OBSI Testing – Cell 7 (Innovative).

Innovative (7)							
Cell 7 Driving Lane							
		Measured			Corrected		
Date/time	Air Temp (°F)	L. Edge	T. Edge	Average	L. Edge	T. Edge	Average
8/17/07 12:00 PM	71.4			101.9			102.0
10/22/07 1:18 PM	53.5	98.5	99.2	98.8	98.3	99.0	98.6
4/2/08 2:10 PM	40.4	99.9	100.7	100.3	99.4	100.3	99.8
12/5/08 11:18 AM	17.5	102.4	103.0	102.7	101.6	102.2	101.9
3/16/09 1:00 PM	58.6	100.9	101.3	101.1	100.8	101.2	101.0
7/21/09 12:16 PM	73.4	99.6	100.2	99.9	99.7	100.3	100.0
9/15/09 5:18 PM	80.7	98.0	98.9	98.5	98.2	99.1	98.7
11/17/09 1:29 PM	49.2	100.6	100.4	100.6	100.3	100.1	100.3
3/8/10 12:31 PM	36.2	101.3	101.1	101.2	100.8	100.6	100.7
7/28/10 2:12 PM	78.4	98.9	99.0	99.0	99.1	99.2	99.1
9/17/10 2:05 PM	64.1	100.0	100.0	100.0	100.0	100.0	100.0
11/17/10 10:59 AM	34.0	102.0	102.5	102.3	101.5	102.0	101.8
3/15/11 9:42 AM	33.1	102.2	101.8	102.0	101.7	101.3	101.5
6/28/11 10:08 AM	67.6	101.9	101.6	101.8	101.9	101.6	101.7

Cell 7 Passing Lane							
		Measured			Corrected		
Date/time	Air Temp (°F)	L. Edge	T. Edge	Average	L. Edge	T. Edge	Average
8/17/07 12:00 PM	71.4			102.5			102.6
10/22/07 1:29 PM	53.7	98.4	99.3	98.9	98.2	99.1	98.7
4/2/08 2:47 PM	40.0	99.7	100.3	100.0	99.2	99.8	99.6
11/20/08 10:40 AM	21.3	102.0	102.5	102.3	101.3	101.8	101.6
3/16/09 12:29 PM	57.5	100.6	101.0	100.8	100.4	100.9	100.7
7/21/09 12:43 PM	74.1	98.5	99.3	98.9	98.6	99.4	99.0
9/15/09 4:39 PM	81.4	97.6	98.6	98.1	97.8	98.8	98.3
11/17/09 1:55 PM	49.6	99.6	99.4	99.5	99.3	99.2	99.2
3/8/10 10:57 AM	35.5	100.4	100.1	100.2	99.9	99.6	99.8
7/28/10 1:32 PM	77.7	98.8	99.2	99.0	98.9	99.3	99.1
9/17/10 2:15 PM	64.1	100.2	100.4	100.3	100.1	100.3	100.2
11/17/10 11:08 AM	34.0	101.9	102.4	102.1	101.3	101.8	101.6
3/15/11 9:42 AM	33.1	101.3	101.2	101.3	100.8	100.7	100.7
6/28/11 10:08 AM	67.6	101.7	101.9	101.8	101.7	101.9	101.8

Table 4. OBSI Testing – Cell 8 (Conventional).

Conventional (8)

Cell 8 Driving Lane

		Measured			Corrected		
Date/time	Air Temp (°F)	L. Edge	T. Edge	Average	L. Edge	T. Edge	Average
8/17/07 12:00 PM	71.4			100.7			100.8
10/22/07 1:18 PM	53.5	103.8	102.8	103.3	103.2	102.2	102.7
4/2/08 2:10 PM	40.4	102.0	101.9	101.9	100.8	100.7	100.8
12/5/08 11:18 AM	17.5	103.9	103.9	103.9	101.8	101.7	101.8
3/16/09 1:00 PM	58.6	102.3	102.1	102.2	101.9	101.7	101.8
7/21/09 12:16 PM	73.4	101.1	101.0	101.1	101.4	101.2	101.3
9/15/09 5:18 PM	80.7	100.5	100.2	100.3	101.0	100.7	100.9
11/17/09 1:29 PM	49.2	102.3	102.0	102.2	101.5	101.2	101.4
3/8/10 12:31 PM	36.2	102.8	102.3	102.6	101.4	101.0	101.2
7/28/10 2:12 PM	78.4	101.1	101.1	101.1	101.6	101.5	101.5
9/17/10 2:05 PM	64.1	103.1	102.8	103.0	102.9	102.7	102.9
11/17/10 10:59 AM	34.0	104.3	104.4	104.4	102.8	103.0	102.9
3/15/11 9:42 AM	33.1	104.2	103.8	104.0	102.7	102.3	102.5
6/28/11 10:08 AM	67.6	103.6	102.9	103.3	103.6	102.9	103.3

Cell 8 Passing Lane

		Measured			Corrected		
Date/time	Air Temp (°F)	L. Edge	T. Edge	Average	L. Edge	T. Edge	Average
8/17/07 12:00 PM	71.4			101.5			101.6
10/22/07 1:29 PM	53.7	103.6	102.8	103.2	103.0	102.2	102.6
4/2/08 2:47 PM	40.0	102.6	102.4	102.5	101.4	101.2	101.3
11/20/08 10:40 AM	21.3	104.4	104.7	104.6	102.4	102.7	102.6
3/16/09 12:29 PM	57.5	102.9	102.9	102.9	102.5	102.5	102.5
7/21/09 12:43 PM	74.1	101.8	101.2	101.5	102.1	101.5	101.8
9/15/09 4:39 PM	81.4	101.4	101.0	101.2	101.9	101.6	101.8
11/17/09 1:55 PM	49.6	102.9	102.5	102.7	102.1	101.7	101.9
3/8/10 10:57 AM	35.5	103.4	103.3	103.4	102.1	101.9	102.0
7/28/10 1:32 PM	77.7	101.4	101.1	101.3	101.8	101.5	101.7
9/17/10 2:15 PM	64.1	103.7	103.4	103.5	103.5	103.2	103.4
11/17/10 11:08 AM	34.0	104.5	104.8	104.7	103.1	103.4	103.2
3/15/11 9:42 AM	33.1	103.4	103.3	103.4	101.9	101.8	101.9
6/28/11 10:08 AM	67.6	103.4	103.2	103.3	103.4	103.1	103.3

Table 5. OBSI Testing – Cell 9 (Ultimate).

Ultimate (9)							
Cell 9 Driving Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
9/10/07 1:06 PM	52.9	103.3	102.7	103.0	103.0	102.4	102.7
12/5/08 11:18 AM	17.5	101.3	102.0	101.7	100.3	101.0	100.7
3/16/09 1:00 PM	58.6	100.9	101.4	101.2	100.7	101.2	101.0
7/21/09 12:16 PM	73.4	100.0	100.3	100.2	100.1	100.4	100.3
9/15/09 5:18 PM	80.7	98.8	99.1	99.0	99.0	99.4	99.2
11/17/09 1:29 PM	49.2	101.2	101.3	101.2	100.9	100.9	100.9
3/8/10 12:31 PM	36.2	102.4	102.3	102.4	101.8	101.7	101.8
7/28/10 2:12 PM	78.4	99.9	100.0	100.0	100.1	100.2	100.2
9/17/10 2:05 PM	64.1	101.8	101.8	101.8	101.7	101.7	101.7
11/17/10 10:59 AM	34.0	103.2	103.6	103.4	102.6	103.0	102.8
3/15/11 9:42 AM	33.1	103.2	103.1	103.2	102.5	102.4	102.5
6/28/11 10:08 AM	67.6	103.0	102.6	102.8	103.0	102.6	102.8

Cell 9 Passing Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
9/10/07 10:52 AM	52.9	104.7	104.4	104.6	104.4	104.1	104.3
11/20/08 10:40 AM	21.3	102.3	102.8	102.6	101.4	101.9	101.7
3/16/09 12:29 PM	57.5	101.5	101.9	101.7	101.3	101.7	101.5
7/21/09 12:43 PM	74.1	100.0	100.4	100.2	100.1	100.5	100.3
9/15/09 4:39 PM	81.4	98.9	99.1	99.0	99.2	99.4	99.3
11/17/09 1:55 PM	49.6	101.0	100.9	101.0	100.7	100.6	100.6
3/8/10 10:57 AM	35.5	101.9	101.9	101.9	101.3	101.3	101.3
7/28/10 1:32 PM	77.7	99.9	99.8	99.9	100.1	100.0	100.0
9/17/10 2:15 PM	64.1	102.3	102.1	102.2	102.2	102.0	102.1
11/17/10 11:08 AM	34.0	103.4	103.9	103.6	102.7	103.3	103.0
3/15/11 9:42 AM	33.1	103.1	103.4	103.2	102.4	102.7	102.6
6/28/11 10:08 AM	67.6	102.6	102.4	102.5	102.6	102.4	102.5

Table 6. OBSI Testing – Cell 12 (Control).

Control (12)							
Cell 12 Driving Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
9/10/07 1:23 PM	52.9	104.6	103.8	104.2	104.3	103.5	103.9
12/5/08 11:06 AM	17.4	106.8	105.9	106.4	105.8	105.0	105.4
7/21/09 12:03 PM	73.1	105.5	104.6	105.1	105.6	104.7	105.2
9/17/10 1:23 PM	63.4	105.9	104.9	105.4	105.8	104.8	105.3
11/17/10 10:45 AM	33.5	106.9	106.2	106.6	106.2	105.5	105.9
3/15/11 9:40 AM	33.1	106.5	105.9	106.2	105.8	105.2	105.5
6/28/11 10:08 AM	67.6	106.0	105.1	105.6	106.0	105.1	105.6

Cell 12 Passing Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
9/10/07 1:23 PM	52.9	105.1	104.8	105.0	104.8	104.5	104.7
11/20/08 10:32 AM	21.2	107.5	106.6	107.1	106.6	105.7	106.2
3/16/09 12:29 PM	57.5	106.3	105.5	105.9	106.1	105.3	105.7
7/21/09 12:03 PM	73.1	105.5	104.7	105.1	105.6	104.8	105.2
9/17/10 1:23 PM	63.4	106.5	105.6	106.1	106.4	105.5	106.0
11/17/10 10:45 AM	33.5	107.1	106.7	106.9	106.4	106.0	106.2
3/15/11 9:40 AM	33.1	106.0	105.7	105.9	105.3	105.0	105.2
6/28/11 10:08 AM	67.6	105.9	105.3	105.6	105.9	105.3	105.6

Table 7. OBSI Testing – Cell 71 (New Ultimate).

New Ultimate (71)							
Cell 71 Driving Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
7/28/10 1:51 PM	77.9	96.8	96.9	96.9	96.9	97.0	96.9
9/17/10 2:28 PM	64.1	98.9	98.8	98.9	98.9	98.8	98.8
11/17/10 11:34 AM	34.1	100.9	101.0	101.0	100.6	100.7	100.6
3/15/11 10:17 AM	33.1	101.1	100.8	101.0	100.8	100.5	100.6
6/28/11 10:08 AM	67.6	100.9	100.4	100.7	100.9	100.4	100.7

Cell 71 Passing Lane							
		Measured			**Corrected**		
Date/time	**Air Temp (°F)**	**L. Edge**	**T. Edge**	**Average**	**L. Edge**	**T. Edge**	**Average**
7/28/10 1:51 PM	77.9	100.3	100.1	100.2	100.4	100.2	100.3
9/17/10 2:28 PM	64.1	101.7	101.4	101.6	101.7	101.4	101.5
11/17/10 11:34 AM	34.1	103.2	103.5	103.4	102.9	103.2	103.0
3/15/11 10:17 AM	33.1	101.2	101.1	101.2	100.9	100.8	100.8
6/28/11 10:23 AM	68.0	101.1	101.1	101.1	101.1	101.1	101.1

Friction

Table 8. Friction Testing – Driving Lane Ribbed Tire.

Driving Lane Ribbed Tire											
Cell	**Age**	**Date**	**Time**	**FN**	**Peak**	**Speed (mph)**	**Air Temp (F)**	**Pvmt Temp (F)**	**Min FN**	**Max FN**	**Slip**
Innovative (7)	-1.5	4/19/2006	11:08 AM	55.7	82.81	40.4	59		51	60	16
	-1.0	10/24/2006	12:00 AM	59.5	78.6	40	42	62.8	0	0	0
	0.0	11/6/2007	10:10 AM	46.1	65.67	40.8	37	45.7	44	48	8
	0.6	5/28/2008	11:15 AM	44.7	66.87	40.4	66	99.3	42	47	16
	1.0	10/31/2008	10:47 AM	45.1	68.54	41.4	68	70.3	43	47	13
	1.7	6/16/2009	11:23 AM	44.6	60.17	40.2	68	93.5	42	48	15
	2.9	9/20/2010	11:24 AM	41.9	67.95	40.1	55	64.4	38	44	12
	3.5	4/14/2011	10:26 AM	46.4	63.85	40.2	37	57.6	44	49	10
Conventional (8)	-1.5	4/19/2006	11:08 AM	60.7	81.89	40.5	59		55	66	17
	-1.0	10/24/2006	12:00 AM	48	64.14	40.3	42	61.7	0	0	0
	0.0	11/6/2007	10:10 AM	55.4	81.24	40.4	36	45.4	52	58	14
	0.6	5/28/2008	11:14 AM	57.75	86.7	40.05	65.5	98.75	54	61	10.5
	1.0	10/31/2008	10:46 AM	54	82.2	41.3	68	69.8	52	56	9
	1.7	6/16/2009	11:23 AM	48.9	75.99	40.3	68	93.2	45	52	18
	2.9	9/20/2010	11:23 AM	48.8	67.2	39.8	55	63.9	44	54	13
	3.5	4/14/2011	10:26 AM	51	72.21	40.1	37	58.1	46	54	12
Ultimate (9)	-2.5	4/19/2006	11:08 AM	66	92.83	40.3	60		62	71	12
	-1.0	11/6/2007	10:10 AM	49.9	79.21	40.9	37	46.9	46	53	15
	-0.4	5/28/2008	11:14 AM	56.25	84.785	39.55	65.5	101.7	51	60	14.5
	0.0	10/31/2008	10:46 AM	48.2	76.29	40.4	68	69.1	43	54	12
	0.7	6/16/2009	11:23 AM	45.3	65.76	40.9	68	92.2	43	48	12
	1.9	9/20/2010	11:23 AM	45.2	64.39	40.4	55	63.2	43	47	14
	2.5	4/14/2011	10:26 AM	50.1	70.53	40.5	38	55.9	48	52	9
Control (12)		10/31/2008	10:46 AM	51.9	76.08	40.2	68	69.8	48	56	9
		9/20/2010	11:23 AM	46.7	69.34	40	55	64.9	41	51	9
		4/14/2011	10:26 AM	47.2	67.94	40.3	38	59.3	39	52	9
New Ultimate (71)	0.4	9/20/2010	11:23 AM	44.9	61.71	40.2	55	64.6	42	48	11
	1.0	4/14/2011	10:25 AM	50.9	63.08	40.1	38	58.1	48	55	13
	1.4	9/29/2011	10:54 AM	41	63.58	40.3	12	75	36	45	11

Table 9. Friction Testing – Driving Lane Smooth Tire.

Cell	Age	Date	Time	FN	Peak	Speed (mph)	Air Temp (F)	Pvmt Temp (F)	Min FN	Max FN	Slip
Driving Lane - Smooth Tire											
Innovative (7)	-1.5	4/19/2006	11:32 AM	26.2	45.26	40.5	60		23	30	13
	-1.0	10/24/2006	12:00 AM	35.9	51.97	40.2	43	63	0	0	0
	0.0	11/6/2007	10:27 AM	45.1	63.08	40.7	37	46.9	41	48	21
	0.6	5/28/2008	11:21 AM	50.2	72.7	42.2	65	96.5	45	54	11
	1.0	10/31/2008	11:10 AM	48.7	79.46	39.8	68	67.8	42	53	13
	1.7	6/16/2009	11:40 AM	46.5	69.86	40.5	68	88	42	54	11
	2.9	9/20/2010	11:40 AM	49	79.27	39.9	55	64.4	45	53	10
	3.5	4/14/2011	10:37 AM	48.3	79.72	40	37	55.5	45	51	10
Conventional (8)	-1.5	4/19/2006	11:32 AM	30.2	37.58	40.5	61		23	42	6
	-1.0	10/24/2006	12:00 AM	20.9	28.87	40.6	43	61	0	0	0
	0.0	11/6/2007	10:27 AM	48.7	75.74	40.3	37	45.9	44	53	9
	0.6	5/28/2008	11:20 AM	58.3	99.28	41.7	65	92.4	52	64	8
	1.0	10/31/2008	11:09 AM	55.3	94.17	40.2	68	68.6	50	60	9
	1.7	6/16/2009	11:40 AM	50.5	81.54	40.6	68	88.8	44	55	14
	2.9	9/20/2010	11:39 AM	43.9	73	40	55	63.4	37	47	10
	3.5	4/14/2011	10:37 AM	49.3	77.91	40	37	55.4	41	55	10
Ultimate (9)	-2.5	4/19/2006	11:32 AM	31.4	54.87	40.5	61		26	37	27
	-1.0	11/6/2007	10:27 AM	39.1	46.77	40.8	36	47.4	34	45	4
	-0.4	5/28/2008	11:20 AM	31.5	45.645	41.7	65	96.75	21.5	43	15
	0.0	10/31/2008	11:09 AM	56.2	86.88	40.3	68	68.3	51	60	9
	0.7	6/16/2009	11:40 AM	48.4	69.55	40.2	68	86.8	45	51	7
	1.9	9/20/2010	11:39 AM	46.8	68.06	40	55	63.2	44	49	8
	2.5	4/14/2011	10:37 AM	51.9	71.61	39.8	37	54.3	50	55	13
Control (12)		10/31/2008	10:46 AM	31.1	52.4	40.1	68	68.6	21	38	26
		9/20/2010	11:23 AM	32.2	50.37	40.1	55	64.4	25	41	30
		4/14/2011	10:26 AM	34.6	50.64	40.3	38	59.4	25	41	10
New Ultimate (71)	0.4	9/20/2010	11:39 AM	47.9	66.38	40.2	55	64.2	44	52	7
	1.0	4/14/2011	10:37 AM	46.8	64.83	40.2	38	55.9	42	51	12
	1.4	9/29/2011	11:06 AM	46.4	66.37	39.9	32	71.3	43	49	14

Table 10. Friction Testing – Passing Lane Ribbed Tire.

Cell	Age	Date	Time	FN	Peak	Speed (mph)	Air Temp (F)	Pvmt Temp (F)	Min FN	Max FN	Slip
Innovative (7)	-1.5	4/19/2006	11:49 AM	57.5	81.56	40.4	60		53	60	15
	-1.0	10/24/2006	12:00 AM	59.4	75.81	40	45	64	0	0	0
	0.0	11/6/2007	10:48 AM	46.2	70.7	40.6	37	48.7	41	49	9
	0.6	5/28/2008	11:37 AM	43.8	66.05	40.7	65	100.9	41	46	13
	1.7	6/16/2009	10:12 AM	41.5	63.1	40.4	68	89.1	37	44	11
	2.9	9/20/2010	12:00 PM	46.7	72.28	40.6	55	66.1	42	50	14
	3.5	4/14/2011	10:50 AM	49.5	67.46	40.4	38	58.1	46	52	7
Conventional (8)	-1.5	4/19/2006	11:48 AM	52.6	80.73	40	61		47	60	14
	-1.0	10/24/2006	12:00 AM	47	68.09	40.1	44	63.3	0	0	0
	0.0	11/6/2007	10:48 AM	55.7	82.84	40.3	37	48.2	50	61	9
	0.6	5/28/2008	11:37 AM	56.6	83.925	40.25	66	98.6	52.5	60.5	14.5
	1.7	6/16/2009	10:12 AM	49.7	75.27	39.7	68	88.8	46	53	13
	2.9	9/20/2010	12:00 PM	54	73.77	40.3	55	65.9	50	57	12
	3.5	4/14/2011	10:50 AM	55.4	73.23	39.1	38	57.9	52	60	14
Ultimate (9)	-2.5	4/19/2006	11:48 AM	54.2	78.43	40.5	62		48	60	24
	-1.0	11/6/2007	10:48 AM	52.9	75.1	41.2	37	48.6	48	57	18
	-0.4	5/28/2008	11:37 AM	53.7	82.545	39.9	67	104.6	50	58	13
	0.7	6/16/2009	10:12 AM	36.3	49.73	40.9	68	87.8	34	40	9
	1.9	9/20/2010	12:00 PM	46.2	62.85	40.5	55	65.4	42	49	19
	2.5	4/14/2011	10:50 AM	48.7	63.69	40.8	38	58.1	45	52	9
Control (12)		9/20/2010	11:23 AM	51.7	71.8	40.4	55	65.9	46	56	20
		4/14/2011	10:26 AM	55.2	72.79	39.9	38	61.1	48	59	26
New Ultimate (71)	0.4	9/20/2010	11:59 AM	49.2	72.34	40.1	55	65.6	45	52	11
	1.0	4/14/2011	10:49 AM	54.5	77.02	39.6	38	58.6	51	58	10
	1.4	9/29/2011	10:41 AM	51.9	75.98	39.7	12	74.7	49	56	12

Table 11. Friction Testing – Passing Lane Smooth Tire.

Passing Lane - Smooth Tire											
Cell	***Age***	***Date***	***Time***	***FN***	***Peak***	***Speed (mph)***	***Air Temp (F)***	***Pvmt Temp (F)***	***Min FN***	***Max FN***	***Slip***
Innovative (7)	-1.5	4/19/2006	12:10 PM	40.4	78.95	40.2	62		30	55	21
	0.6	5/28/2008	11:43 AM	47	71.28	40.7	65	97.7	43	52	9
	1.7	6/16/2009	10:29 AM	48.4	72.24	40.3	68	90.8	43	52	9
	2.9	9/20/2010	12:15 PM	51.1	74.76	40.3	55	64.4	45	54	13
	3.5	4/14/2011	11:01 AM	55.5	87.16	40.2	38	60.5	50	60	11
Conventional (8)	-1.5	4/19/2006	12:09 PM	28	81.77	39.9	62		17	49	10
	0.6	5/28/2008	11:43 AM	58.1	106.195	40.2	66	98.0	52	65	10
	1.7	6/16/2009	10:28 AM	55	90.97	39.7	68	89.3	50	62	9
	2.9	9/20/2010	12:15 PM	55.1	79.41	39.7	55	64.6	50	62	12
	3.5	4/14/2011	11:01 AM	54	79.39	40.5	39	56.6	40	64	18
Ultimate (9)	-2.5	4/19/2006	12:09 PM	44.5	81.27	40.4	62		36	57	7
	-0.4	5/28/2008	11:43 AM	38.5	59.065	40.3	66	102.3	28	52	24
	0.7	6/16/2009	10:28 AM	41.1	56.19	40.4	68	91.3	36	46	12
	1.9	9/20/2010	12:15 PM	45.1	63.55	40.4	55	64.2	43	48	12
	2.5	4/14/2011	11:01 AM	51.3	80.38	40.3	39	57.5	43	64	9
Control (12)		9/20/2010	12:14 AM	41.7	53.81	40.4	55	65.9	35	49	6
		4/14/2011	10:26 AM	51.8	83.77	40.3	39	63.9	38	68	15
New Ultimate (71)	0.4	9/20/2010	12:14 PM	47.9	81.03	40.2	55	65.4	43	51	6
	1.0	4/14/2011	11:00 AM	50.8	79.19	40.4	39	59.3	40	59	13
	1.4	9/29/2011	11:17 AM	47	89.15	39.9	32	73.8	39	53	6

Texture Depth

Table 12. Average Texture Depth.

	Date	MTD Passing Lane (mm)	MTD Driving Lane (mm)
Innovative (7)	10/15/2007	0.45	0.41
	10/23/2007	0.95	0.98
	11/2/2008	0.56	0.69
	3/15/2009	0.62	0.65
	6/1/2010	0.58	0.67
Conventional (8)	10/15/2007	0.45	0.41
	10/23/2007	1.60	**1.55**
	11/2/2008	1.02	0.74
	3/15/2009	0.89	0.69
	6/1/2010	0.71	0.69
Ultimate (9)	10/25/2008	2.16	1.98
	3/15/2009	1.91	1.71
	6/1/2010	1.69	1.49
New Ultimate (71)	6/1/2010	0.88	1.11
	10/20/2010	0.83	0.99
	6/24/2011	0.57	1.06
	10/27/2011	0.57	1.17