Minnesota Local Road Research Board (LRRB)
Investigation 864 and, MPR Project No. 6-(022)

Recycled Asphalt Pavement:

MnROAD Study of Fractionated RAP

Interim Report:

Annual Monitoring and Performance Report for Year 4

Submitted to the LRRB and FHWA technical advisory panels in fulfillment of Task 7 on May 29, 2012

Revised and submitted for approval on June 15, 2012

Eddie N. Johnson, Research Project Engineer
MnDOT Office of Materials and Road Research
1400 Gervais Avenue, Maplewood, Minnesota 55109

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Objectives of Report and Research

This report represents task 7 of Local Road Research Board (LRRB) project number 864, Minnesota State Planning and Research project number MPR 06-(022) study entitled, “Recycled Asphalt Pavement: MnROAD Study of Fractionated RAP”. This report will summarize the continued performance monitoring activities conducted on the Recycled Asphalt Pavement (RAP) and Fractionated Recycled Asphalt Pavement (FRAP) test cells at the Minnesota Road Research Project (MnROAD). The report will present the early performance results of more than three years of routine seasonal monitoring activities, which include: distress surveys, rutting and ride measurements, as well as Falling Weight Deflectometer (FWD) testing, and surface characteristics measurements of noise and friction.

Study Cells and the Minnesota Road Research Project (MnROAD)

The Minnesota Road Research Project (MnROAD) is operated by the Minnesota Department of Transportation (MnDOT). MnROAD consists of two unique road segments located parallel to Interstate 94 (2):

- A 3.5-mile Mainline (ML) interstate roadway carrying “live” traffic averaging 28,500 vehicles per day with 12.7 % trucks (Westbound only).
- A 2.5-mile closed-loop Low Volume Road (LVR) carrying a MnROAD-operated 18-wheel, 5-axle, 80,000-lb tractor-semi-trailer to simulate the conditions of rural roads.

During 2008 portions of MnROAD were reconstructed as part of SP 8680-157 (2). Under this project, a total of eleven FRAP and RAP test cells were constructed as detailed in the task 2 summary report of this project (3). All but one of the test cells were constructed on the mainline (ML), or interstate portion of MnROAD. Cell 24 was constructed on the closed loop, low volume road (LVR). The lengths of the test cells varied from 550 to 595 feet. Table 1.1 shows the experimental variables and test cell designations.

The HMA surface mixture types are denoted according to MnDOT’s 2008 specifications and can be summarized as follows: All mixtures were SuperPave or Gyratory design (denoted SP) and all had a maximum aggregate size of ¾-in. (19.0 mm), and a nominal maximum aggregate size of ½-in. (12.5 mm). HMA denotes Hot Mixed Asphalt and WMA denotes Warm Mix Asphalt. The mixtures designs were based on 3 to <$10*10^6$ ESALS. All wear course mixtures had target air voids of 4.0% and non-wear course mixtures had a target air voids content of 3.0%. The binder Performance Grade (PG) included 64-34, 58-34, or 58-28. The thicknesses, in inches, of the pavements are denoted as follows: total thickness (non-wear course thickness + wear course thickness).

Figure 1.1 and Figure 1.2 show the relative location of the RAP/FRAP study cells (highlighted in red) on ML and LVR.

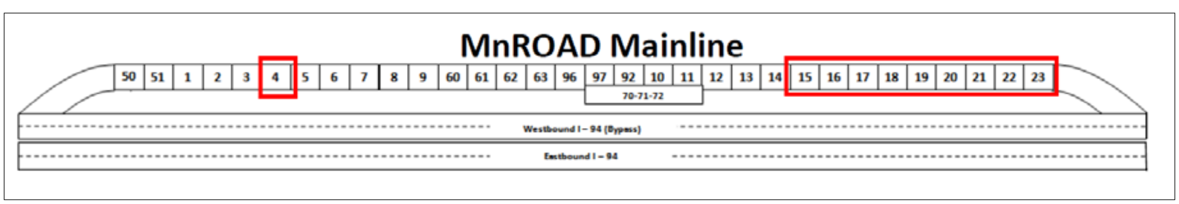

Figure 1.1. MnROAD Mainline (ML)

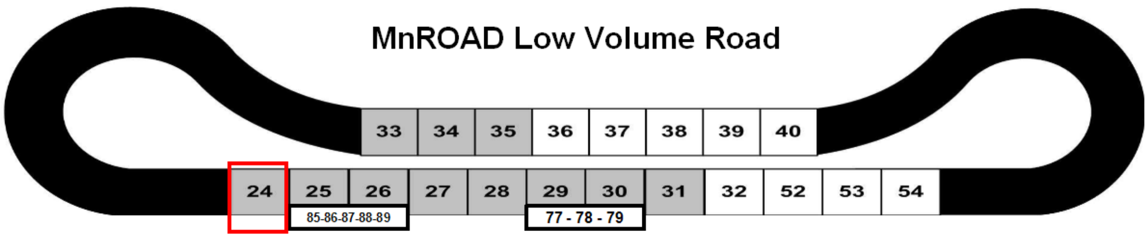

Figure 1.2. MnROAD Low Volume Road (LVR)

Table 1.1. HMA Designation and Experimental Variables

Cell No.	HMA Mix Type: 12.5mm Dense Graded SuperPave	PG Binder Grade	RAP, %	Thick (in)
4	HMA	64-34	0%	3
15	WMA	58-34	20%	3[a]
16	WMA	58-34	20%	5 (2 + 3)
17	WMA	58-34	20%	5 (2 + 3)
18	WMA	58-34	20%	5 (2 + 3)
19	WMA	58-34	20%	5 (2 + 3)
20	HMA	58-28	30%	5 (2 + 3)
21	HMA + FRAP	58-28	30%[b]	5 (2 + 3)
22	HMA + FRAP	58-34	30%[b]	5 (2 + 3)
23	WMA	58-34	20%	5 (2 + 3)
24	HMA	58-34	20%	3

[a] 3-in. mill and fill over badly cracked HMA.
[b] RAP was split on ¼" screen.

The thickness of the asphalt, aggregate base, subbase, and granular fill layers were identical in Cells 19 through 23. Figure 1.3 shows the materials and layer thicknesses for Cells 20 through 22 (2).

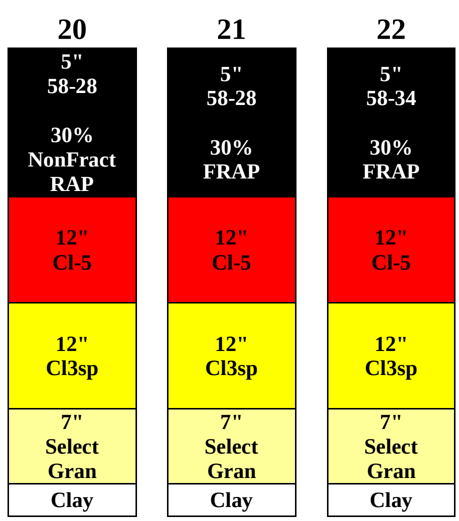

Figure 1.3. Typical Sections for the MnROAD Phase II FRAP study.

In the remaining bituminous cells warm mix was placed in a continuous mat that included Cells 15 – 19 and 23. The Cell 24 mix used the same construction materials, except it was produced at hot mix temperatures. PG 58-34 asphalt was used in all of the cells except for Cell 4, which differed by using PG 64-34 no RAP, and was produced as hot mix. The map of typical sections (Figure 1.4) shows that although base materials vary, Cells 16 – 23 are similar to the FRAP cells with respect to layer thickness of the surface, base, subbase, and subgrade materials.

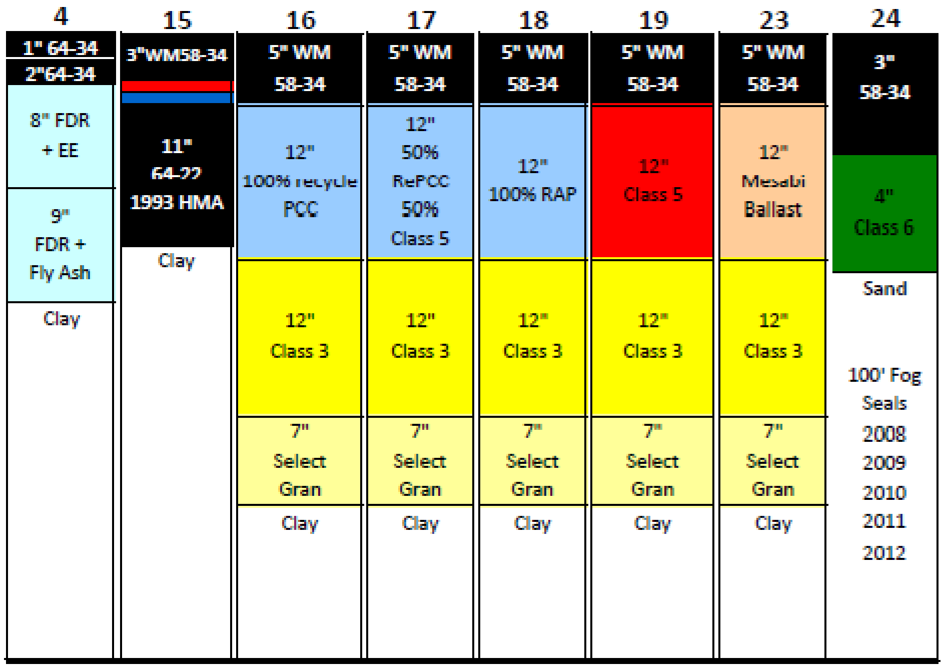

Figure 1.4. Typical sections for eight MnROAD Phase II bituminous cells.

Current MnDOT Specifications on RAP usage in HMA

The 2011 version of the MnDOT standard specifications for construction (4) was referenced for the current standards and guidelines on the use of RAP. The gyratory design specification requires that the composite RAP and virgin aggregates meet the composite fine aggregate angularity for the mixture being produced, as well as the appropriate aggregated quality tests.

According to the specifications, the maximum allowable recycled asphalt binder content is governed by a requirement for 70% virgin asphalt binder relative to the total binder content. This requirement was new in 2011, and affects all mixtures using any combination of RAP and recycled asphalt shingles (RAS). For all mixtures containing RAP, the asphalt binder must be selected in accordance with Table 1.2. MnDOT's maximum allowed amount of RAS is 5% by weight. When the maximum amount of RAS is used this generally restricts the amount of RAP to 10% (6).

Table 1.2. MnDOT Asphalt Binder Selection Criteria for all Mixtures with RAP

Specified PG Asphalt Binder Grade	RAP Percentage	
	$\leq$ 20% RAP	$\geq$ 20% RAP
PG XX-28 & PG 52-34	Use Specified Grade	Use Specified Grade
PG XX-34	Use Specified Grade	Use Blending Chart*

The specification currently has no provision related to the use of RAP and warm mix, and allowable RAP percentages are not adjusted based on fractionating.

Chapter 2: Pavement Performance

Introduction

This chapter presents the pavement performance monitoring activities conducted to evaluate each cell based upon: visual distress surveys, ride and rutting measurements.

Visual Distress Survey

All MnROAD cells were visually evaluated using a rating system based upon the long term pavement performance (LTPP) evaluation method (7) for a total of 17 different distresses: cracking (9 types), patching/potholes (2 types), surface deformation (2 types), surface defects (3 types) and pumping. Table 2.1 shows the distress name and type, how the distress was measured, and the applicable severity levels. All cells were rated twice annually, once in the spring and once in the fall for a total of 8 evaluations between November 2008 and April 2012.

Table 2.1. LTPP Distress Ratings for Asphalt Concrete Surfaces (7)

Distress	**Unit of Measure**	**Severity Levels)**
Cracking		
1. Fatigue	Area	Yes (3)
2. Block Cracking	Area	Yes (3)
3. Edge	Length	Yes (3)
4. Longitudinal (Wheel Path)	Length	Yes (3)
5. Longitudinal (Non-Wheel Path)	Length	Yes (3)
6. Longitudinal Sealant Det. (Wheel Path)	Length	Yes (3)
7. Longitudinal Sealant Det. (Non-Wheel Path)	Length	Yes (3)
8. Transverse Cracking	Number & Length	Yes (3)
9. Transverse Sealant Det.	Number & Length	Yes (3)
Patching/Potholes		
10. Patching	Number & Area	Yes (3)
11. Pot Holes	Number & Area	Yes (3)
Surface Deformation		
12. Rutting	Depth	No
13. Shoving	Number & Area	No
Surface Defects		
14. Bleeding	Area	No
15. Polished Aggregate	Area	No
16. Ravelinig	Area	Yes (3)
Other Distresses		
17. Pumping	Number & Length	No

Table 2.2 displays the results of the most recent visual distress survey, completed April, 2012. Distress was visible in Cells 15, 16, 20, 21, and 23. If distresses are not present in the tables, then they were not observed in the cell at the time of the survey, i.e. the only distress observed thus far is low severity transverse cracking. The location and severity of each distress within the cells is recorded on distress maps.

Table 2.2. Low Severity Transverse Cracking

Cell/Lane	Rating Date	No. of Cracks	Transverse Crack Length (ft)	Longitudinal Crack Length (ft)
15/Driving	Spring 2009	17	105	0
15/Passing		6	57	0
15/Driving	Fall 2009	16	110	0
15/Passing		7	70	0
15/Driving	Spring 2010	18	128	0
15/Passing		8	77	0
16/Driving		1	6	0
16/Passing		1	12	0
15/Driving	Fall 2011	17*	136	0
15/Passing		10	93	0
16/Driving		2	18	0
16/Passing		1	12	0
20/Driving		1	2	0
20/Passing		0	0	0
21/Driving		1	4	0
15/Driving	Winter 2011-2012	34*	182	0
15/Passing		13	117	0
Other cells		Not rated	Not rated	Not rated
15/Driving	Spring 2012	25	200	0
15/Passing		12	114	0
16/Driving		2	18	0
16/Passing		1	12	0
20/Driving		1	2	0
20/Passing		0	0	0
21/Driving		1	4	0
21/Passing		0	0	13
23/Passing		0	0	7

(*) Cell 15 was re-inspected during regularly scheduled winter and spring lane closures to see if healing was occurring.

Cell 15 was constructed as an overlay (3-inches) placed over a deteriorated full depth asphalt pavement (11.1-inches over clay subgrade). Cell 15 has continued to exhibit the most significant cracking although some variation in visual distress has been noted between seasons. Figure 2.1 and Figure 2.2 show the transverse cracks development, in terms of total number and total length, with time, respectively for Cell 15.

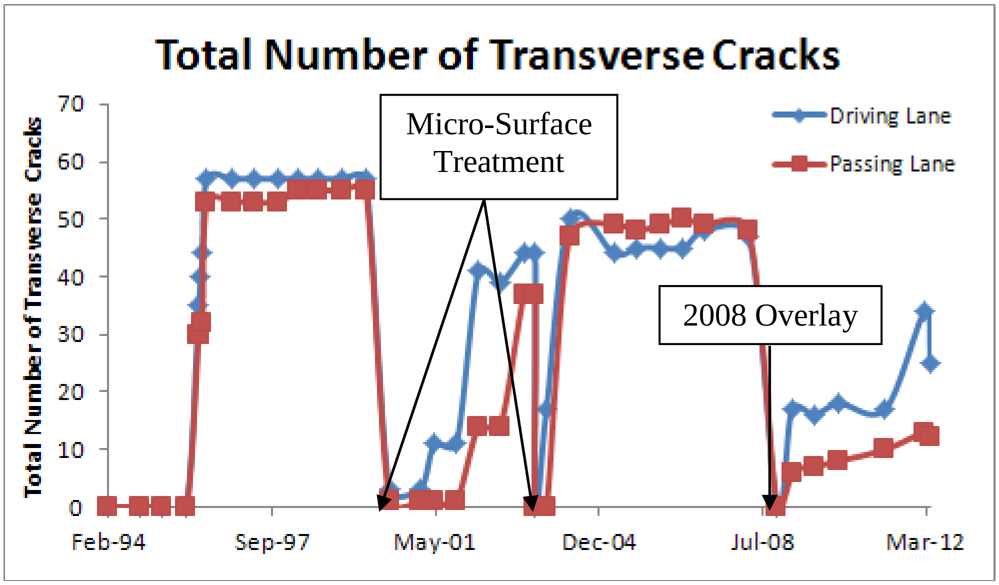

Figure 2.1. Total Number of Transverse Cracks vs. Time for Cell 15

If the transverse cracks present in the new overlay are assumed to be reflective, then it appears that (25/44) or 57% of the underlying cracks have reflected through from the driving lane, and (12/37), or 32% of the cracks have reflected through from the passing lane. Examining the total length of cracks (recall that the total length of the cell is 573 feet), 200/408 feet, or 49%, have reflected through the driving lane, and 114/352 feet, or 32% have reflected through the passing lane. This suggests that more transverse cracks can be expected to reflect through.

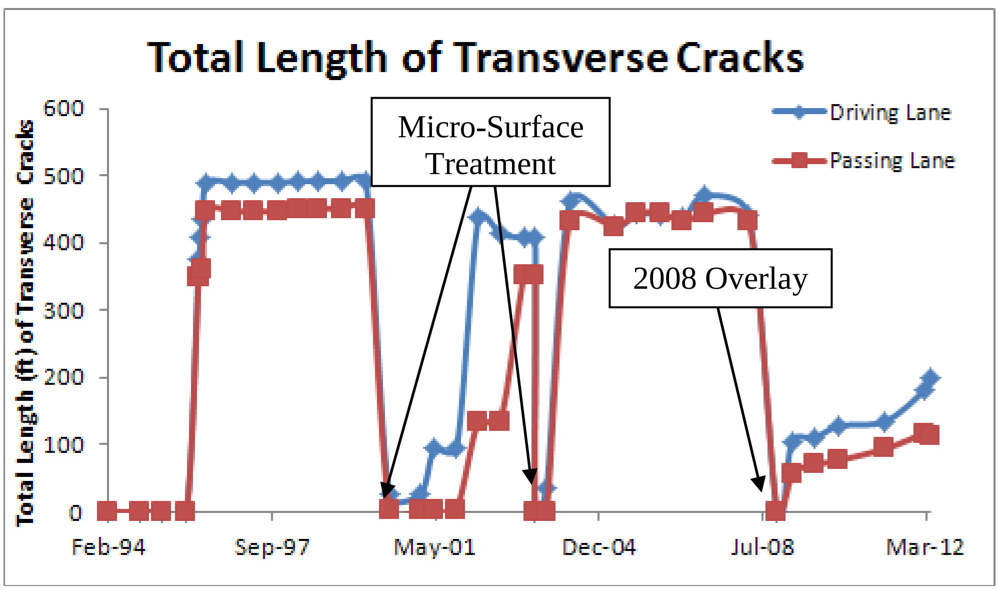

Figure 2.2. Total Length of Transverse Cracks vs. Time for Cell 15

Cell 16 materials include PG 58-34 asphalt binder and 20% RAP. The cell had developed 12 additional feet of cracking. Some cracking occurred directly over a lysimeter that was installed in the class 3 base layer. The cell will be closely monitored to see if additional cracks develop. Cell 20, containing stiffer binder (PG 58-28) and 10% more RAP (30% total), also began to exhibit distress.

Ride

This international ride standard simulates a standard vehicle traveling down the roadway and is equal to the total anticipated vertical movement of the vehicle accumulated over the length of the section. The IRI is typically reported in units of inches/mile (vertical inches of movement per mile traveled). If a pavement were perfectly smooth, the IRI would be zero (i.e. no vertical movement of the vehicle). The higher the IRI is, the rougher the roadway (9).

Ride was measured in both the left and right wheel paths of the driving and passing lanes using a certified laser profiler: an Ames light weight inertial surface analyzer (LISA). LISA measurements were made with a Triad (3-point) laser, and have been made three times annually, spring, summer and fall since construction of the test cells. A total of ten (10) measurements were performed on LVR Cell 24 and twelve (12) on the remaining ML cells between October 2008 and March 2012. A summary of IRI values vs. time for each study cell, lane, and wheel path is presented in Figure 2.3 to Figure 2.5. Note the apparent absence of seasonal influence on roughness data during March 2012. This effect on performance was possibly due to unusually warm weather at MnROAD from November 2011 through March 2012.

Cells 4 and 15 experienced relatively large fluctuations in ride values, peaking at over 160 in/mile during 2011 spring measurements. The most dramatic spikes in Cells 4 and 15 occurred near the roadway centerline, in the left wheel path of the driving lane and right wheel path of the passing lane. Those values subsequently declined below 110 in/mile. These large variations were not seen in any of the other cells. These high fluctuations were determined to not be outliers as they have occurred at the same time in the past three years. This trend will be observed to see if it continues. Recall that Cell 4 was a 3-in. HMA pavement constructed over 8-in. of full depth reclamation stabilized with engineered emulsion, above 9 in. of clay stabilized with fly ash. Cell 15 was a HMA overlay over a full depth HMA pavement constructed directly over a clay subgrade, any movement in the underlying pavement would be observed in the overlay.

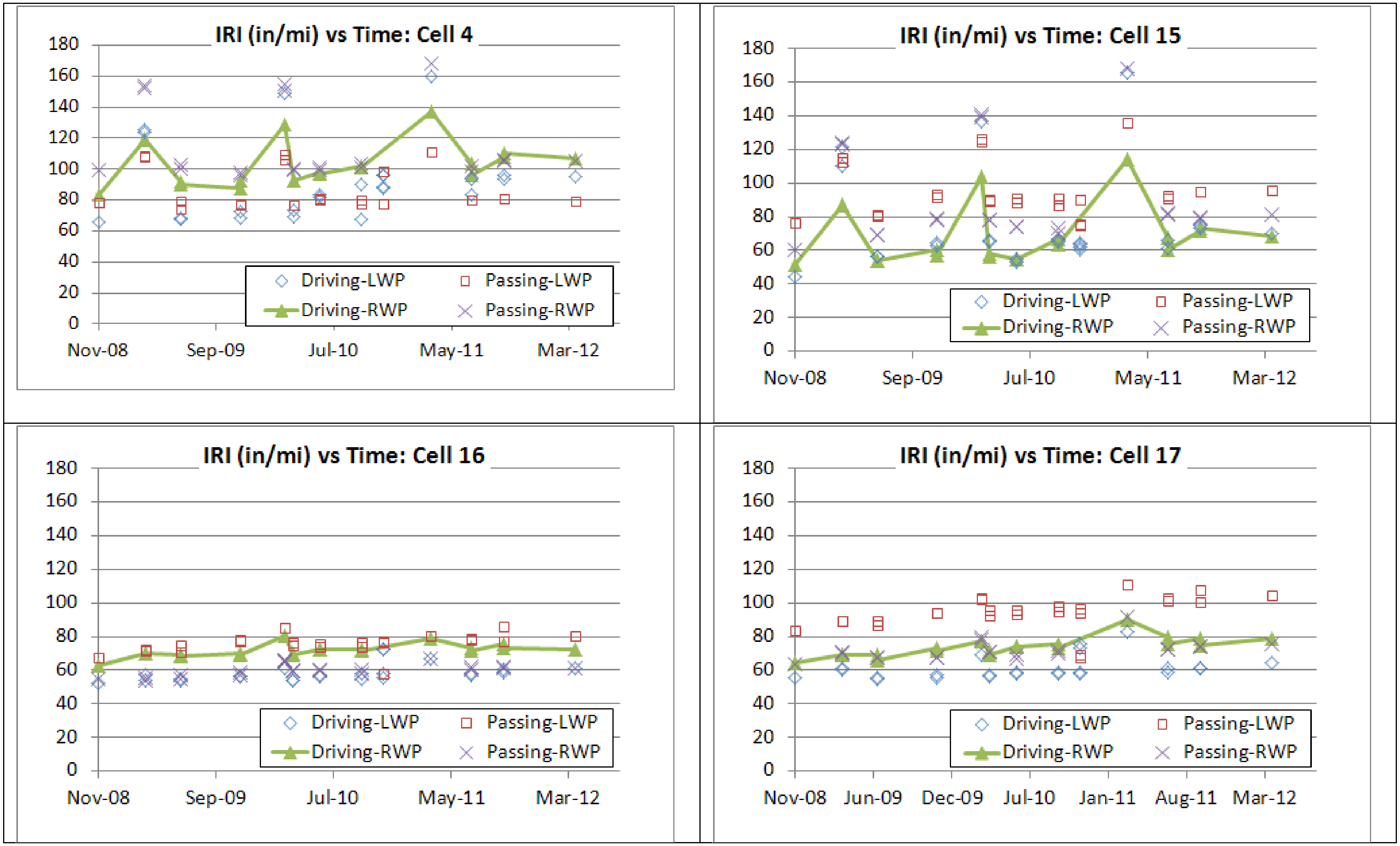

Figure 2.3. IRI vs. Time for Cells 4 - 17

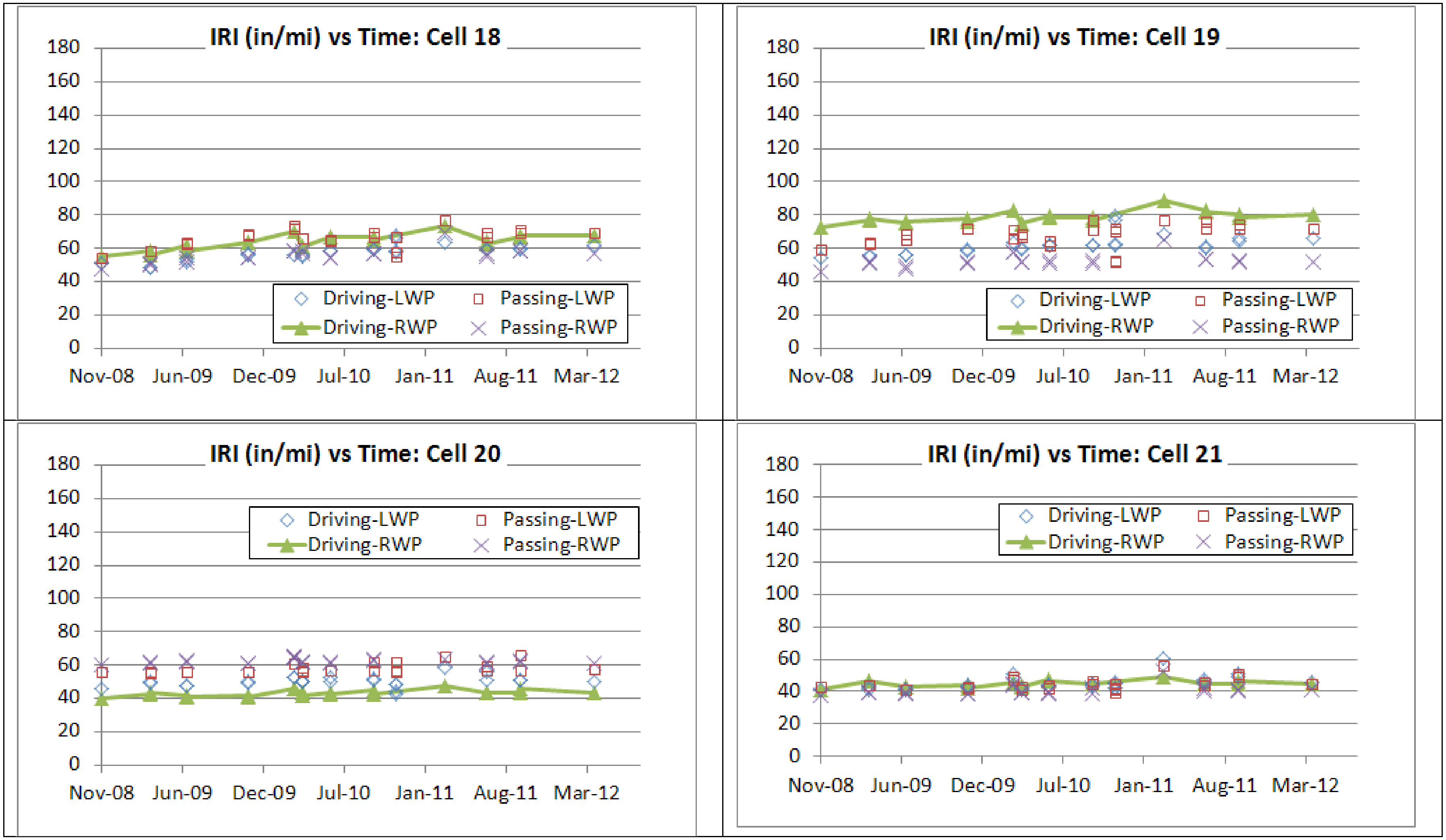

Figure 2.4. IRI vs. Time for Cells 18 - 21

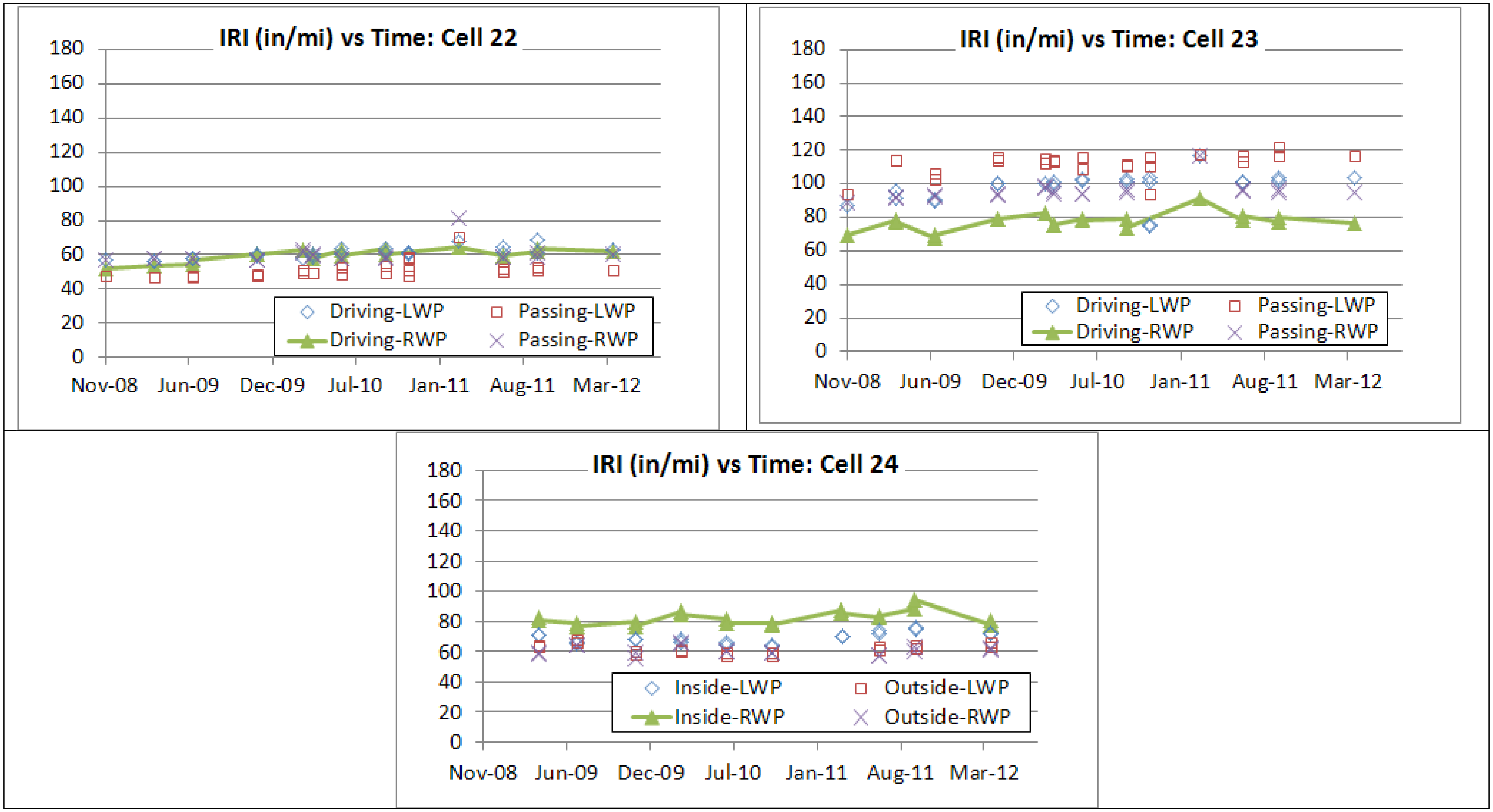

Figure 2.5. IRI vs. Time for Cells 22 - 24

Each test cell was constructed with different initial ride values. Table 2.3 shows the summary statistics of the change through time of the ride values, averaged across the left and right wheel paths and the driving and passing lanes of all study cells. These statistics excluded the yearly peak ride values measured during the spring-thaw period. The decay is the current IRI value subtracted from the initial IRI value (inches/mile), and represents a time period from November 2008 through March 2012.

Table 2.3. Summary Statistics and 3.5-Year Decay of Average Ride Values (non-Spring-Thaw)

Study Group	**Cell**	**Initial**	**2012 Final**	**Decay**	**Yearly Rate**
HMA	4 (Clay & cement)	81.6	96.6	14.9	4.3
WMA	15 (Overlaid full-depth)	58.2	78.9	20.7	5.9
WMA & Recycled Unbound Base	16 (PCC)	59.5	68.9	9.4	2.7
	17 (50/50)	67.0	81.1	14.1	4.0
	18 (RAP)	52.0	64.0	12.0	3.4
WMA	19 (PG-34)	58.2	67.3	9.1	2.6
HMA-FRAP	20 (PG-28)	50.5	53.0	2.5	0.7
	21 (PG-28)	40.6	44.1	3.5	1.0
	22 (PG-34)	53.4	59.2	5.8	1.7
WMA	23 (Taconite base)	84.8	97.9	13.1	3.7
HMA	24 (Aging)	68.8	69.3	0.5	0.2

Cells that have similar construction and base characteristics, as described in Chapter 1, were categorized into study groups. As in previous years, the ride decay of the cells within the recycled unbound base group appears to be very similar. The decay values of the cells within the FRAP/low temperature cracking group also appear to be relatively low and very similar. Cell 15 (mill and overlay of full-depth asphalt) has the highest decay value, and experienced the greatest decline in IRI, followed by Cells 4, 17, and 23. Cells 20 – 22 and 24 appear to have experienced the smallest decline in IRI. It appears to be too early to draw any conclusions on the ride performance related to: FRAP, the proportion of RAP, and virgin binder PG grade as well as the use of WMA technology.

Rutting

Rutting can be defined as a longitudinal surface depression in the wheel path (7). Rutting is an important indicator of performance, as excessive rutting can cause water to remain in wheel-paths and lead to potential issues with vehicle control. Mixture rutting is influenced by insufficient compaction (i.e. high air voids), excessively high asphalt content, excessive mineral filler, or insufficient amount of angular particles (11).

The Automated Laser Profile System (ALPS) was used to characterize the rutting of all study cells. The ALPS collected rutting measurements in both wheel paths of both lanes at 50-ft intervals, with measurements stored every 0.25 in. along the transverse profile. Measurements were performed:

- Five times in 2009 on LVR, and four times on ML
- Three times in 2010 (LVR and ML)
- Three times in 2011 (LVR and ML)

The distribution of this data was examined using a box and whisker plot. Figure 2.6 clearly shows the distribution of the data, which can be judged by the height of the box and length of the whiskers; the extreme values observed can most likely be described as outliers, which skew the data set. Several cells appear to have outliers; however the most extreme condition occurs in Cell 24.

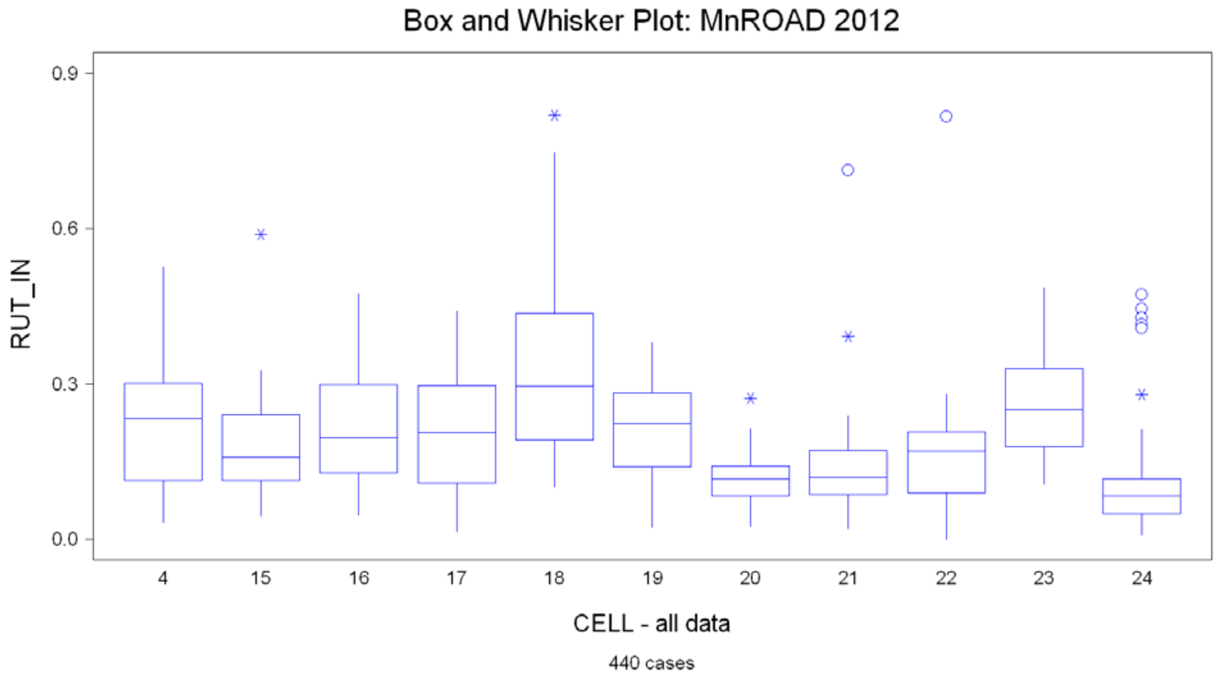

Figure 2.6. Box and Whisker Plot of Rutting Values by Cell

The suspected outliers were removed from the data set using the 1.5IQR Rule (8), as shown by Equation 1.

$$Outlier_{cell} < Q_1 - 1.5 \times IQR, or$$
$$Outlier_{cell} > Q_3 + 1.5 \times IQR \qquad \text{Equation 1}$$

Where:

Q_1 is the 25^{th} percentile measurement for a particular cell
Q_3 is the 75^{th} percentile measurement for a particular cell
IQR is the Interquartile Range ($Q_3 - Q_1$) for a particular cell

Figure 2.7 and

Table 2.4 show the distribution of the data after the 17 outliers (~4% of data set) were removed from nine cells. The top of the box represents the 75th percentile, the middle of the box represents the median value of the data set and the bottom of the box represents the 25th percentile.

Table 2.4. Conditioned Rutting Data - 2012

Cell	N	Med	Max	Limiting 1.5*IQR	New N	New Min	New Med	New Max
4	40	0.23	0.53	0.53	39	0.03	0.23	0.43
15	40	0.16	0.59	0.35	39	0.04	0.16	0.33
16	40	0.20	0.47	0.46	39	0.05	0.19	0.37
17	40	0.21	0.44		40	0.01	0.21	0.44
18	40	0.30	0.82	0.68	38	0.10	0.28	0.64
19	40	0.22	0.38		40	0.02	0.22	0.38
20	40	0.12	0.27	0.21	38	0.02	0.11	0.18
21	40	0.12	0.71	0.25	38	0.02	0.11	0.24
22	40	0.17	0.82	0.37	39	0.00	0.17	0.28
23	40	0.25	0.49		40	0.11	0.25	0.49
24	40	0.08	0.47	0.19	33	0.01	0.07	0.15
All Cells	440	0.17	0.82	0.41	423	0.11	0.16	0.64

According to MnDOT's pavement management practice, the pavement distress rating is impacted only when rutting values are greater than 0.5 in. During 2012, with the exception of Cell 18, all of the cells had rutting values below the 0.5-in. threshold value, and 75% of the all conditioned data were below 0.2577 in.

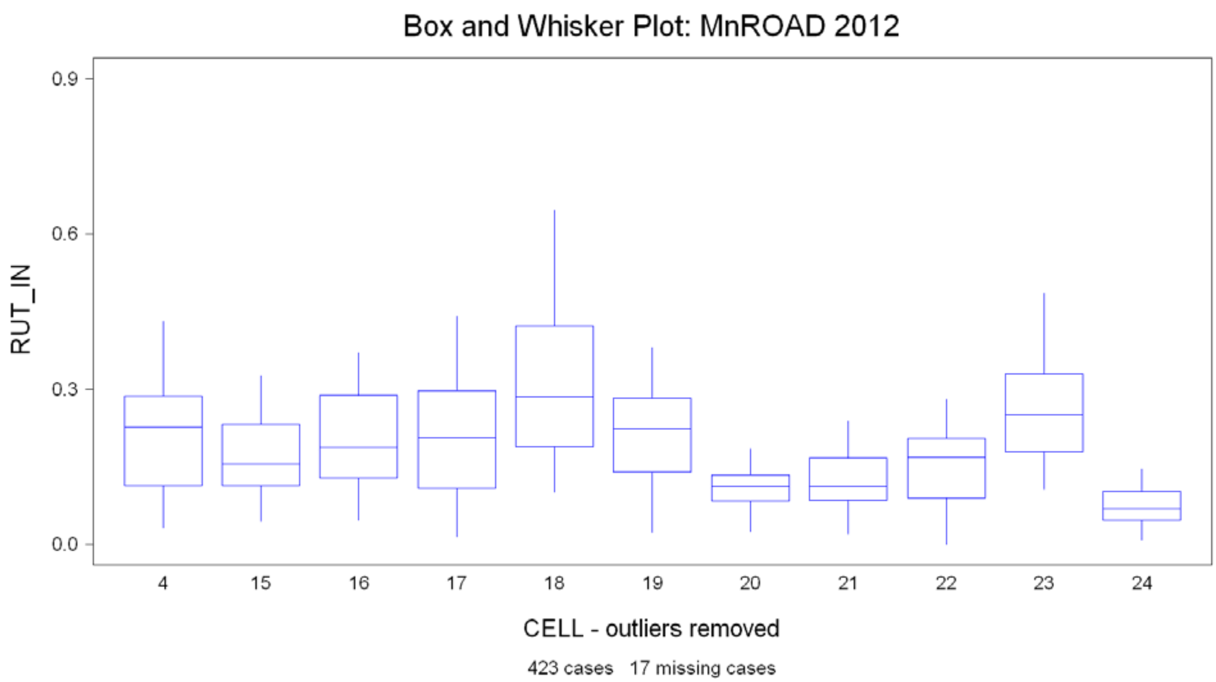

Figure 2.7. Box and Whisker Plot of Rutting Values by Cell with Outliers Removed

Summary of Pavement Performance

The study cells have been evaluated using common performance indicators to assess whether or not the experimental variables of: FRAP, varying proportions of RAP, and grades of virgin asphalt binder, as well as the use of warm mix asphalt technology had a measureable influence on pavement performance. The performance indicators used included: a visual assessment of pavement surface distresses, as well as ride and rutting measurements. Overall, the relatively short service lives of the study cells currently limits the conclusions that can be drawn about their performance, related to the experimental variables. The visual distresses, ride and rutting were not observed to be influenced by the experimental variables.

The pavement distress survey revealed that only one cell (Cell 15) is experiencing substantial distresses, and this is related to the underlying pavement that it was constructed on and not the experimental variables. Two cracks were observed in Cell 16, but underlying instrumentation was assumed to be an influence in crack development. At the time of this report, only limited amounts of distress were observed in cells 16, 20, 21, and 23. With regard to experimental variables, Cell 21 (PG58-28 FRAP) has developed 13ft of longitudinal cracking.

An analysis of ride measurements revealed that the test cells had different initial ride values, and over the measurement history two (cells 4 and 15) were prone to experience substantial variation in coinciding with spring-thaw. It was thought that this behavior was related to factors underlying the pavement, and not to the pavement surface itself. The decay of the ride (IRI) over the performance history of the cells was examined. This revealed that performance was similar within study groups: i.e., WMA, FRAP and Recycled Base (***Table 2.3***).

Rutting results revealed that rutting was not an issue for any of the study cells as measured by the ALPS laser. Only in one case (Cell 18) did rutting measurements exceed 0.5 in. (the value at which rutting impacts a pavements distress rating). Rutting statistics for Cell 18 show the respective median and maximum values were equal to 0.28 and 0.64 in. Future work should include rutting performance checks for study groups related to Cell 18. A cursory comparison of the 2012 FWD data found that the maximum deflections for Cell 18 were within the range measured for the other ten cells.

The pavements are over three years old, and only one study cell was constructed as an overlay. The influence of the experimental variables may become more apparent as the study progresses and the pavements experience more traffic and environmental loadings.

Chapter 3: Pavement Monitoring and Testing

Falling Weight Deflectometer (FWD)

FWD data was collected on all of the bituminous cells in the months following construction. It is well documented that FWD results for bituminous pavements are influenced by base condition (saturated, frozen, unfrozen) and temperature. Because of this, comparisons focused primarily on FWD data collected in the late summer and fall months, when base materials were likely to be stable and surface temperatures relatively moderate. Additionally, the normalized Area Factor was used to draw conclusions about performance similarities of the bituminous cells following construction.

$$AreaFactor = 6\left(1 + 2\left(\frac{D_{12}}{D_0} + \frac{D_{24}}{D_0}\right) + \frac{D_{36}}{D_0}\right) \qquad \text{Equation 2}$$

Where:

D_0 = Deflection measured at the center of FWD load plate
D_{12} = Deflection measured 12 in. (305 mm) from the center of FWD load plate
D_{24} = Deflection measured 24 in. (610 mm) from the center of FWD load plate
D_{36} = Deflection measured 36 in. (914 mm) from the center of FWD load plate

Area Factor

Because of scheduling priorities at MnROAD, FWD data was unavailable for the timeframe between 2008 construction and April 2009. Because of base thaw-recovery issues, structural comparisons were based on the FWD dataset collected from summer through fall. The "Year 1" structural comparison was based on the FWD dataset collected from August to September 2010. Figure 3.1 shows the Area Factors analyzed from FWD data collected in the outer wheel path of the driving lane during the fall seasons of 2009 through 2011. Note that in all cases, the 2010 data indicated a decline in Area Factor. Note also that the relative relationships among the cells appear to be the same during all years. For example, the deflection basin of Cell 15 regularly produced the highest Area Factor.

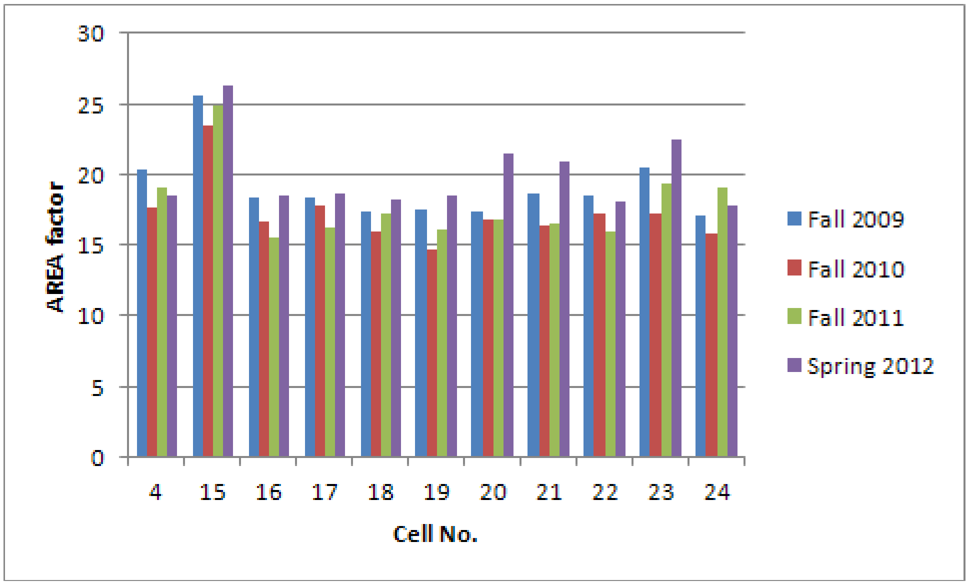

Figure 3.1. Average Area Factor from MnROAD driving lane, Outer Wheel Path

The average Area Factor for the study cells was 19.0 for the fall of 2009, and 19.6 for the spring of 2012. In 2009, all but two (Cells 15 and 24) of the cells had Area Factors within 10 percent of the average. In spring 2012 they were joined by Cell 23.

Cell 15 produced the maximum Area Factors, indicating that the values of D12, D24, and D36 were somewhat similar to D0. The FRAP, HMA and WMA cells produced similar Area Factors. Based on the Area Factor, the deflection basins of these cells were similar.

Table 3.1. Comparison of Average Area Factors, MnROAD

	Fall 2009				Fall 2010				Fall 2011				Spring 2012			
Cell	Avg Area Factor	Stdev	Count	% Above Average	Avg Area Factor	Stdev	Count	% Above Average	Avg Area Factor	Stdev	Count	% Above Average	Avg Area Factor	Stdev	Count	% Above Average
4	20.3	2.235	60	6.6%	17.6	0.7898	15	2.3%	19.0	2.194	60	6.6%	18.5	1.686	90.0	-7.1%
15	25.6	2.175	30	34.4%	23.5	1.9775	30	36.6%	24.9	1.384	30	39.2%	26.3	2.048	30.0	32.1%
16	18.4	1.413	30	-3.4%	16.7	1.2976	30	-2.9%	15.5	1.420	60	-13.1%	18.4	0.704	30.0	-7.5%
17	18.3	1.464	30	-4.0%	17.8	0.5703	15	3.5%	16.2	2.206	60	-9.5%	18.7	0.819	30.0	-6.4%
18	17.4	2.2	30	-8.5%	15.9	0.6154	15	-7.6%	17.2	0.479	15	-3.5%	18.1	0.565	30.0	-9.0%
19	17.5	1.807	30	-8.1%	14.7	0.6929	15	-14.5%	16.0	1.088	45	-10.2%	18.4	0.502	30.0	-7.5%
20	17.3	2.469	45	-9.1%	16.8	0.649	15	-2.3%	16.9	2.417	45	-5.6%	21.5	0.321	30.0	7.8%
21	18.6	2.6	60	-2.1%	16.3	0.6552	15	-5.2%	16.5	2.567	45	-7.8%	20.9	0.345	15.0	5.0%
22	18.5	1.489	30	-2.8%	17.2	0.5665	15	0.0%	15.9	2.442	45	-10.8%	18.1	1.880	75.0	-9.3%
23	20.4	1.996	30	7.3%	17.2	1.113	15	0.0%	19.3	2.378	57	8.1%	22.5	0.693	30.0	12.9%
24	17	2.934	30	-10.4%	15.8	0.8723	15	-8.1%	19.0	1.780	27	6.6%	17.7	1.259	30.0	-11.1%
Total	**19**				**17.2**				**17.9**				**19.9**			

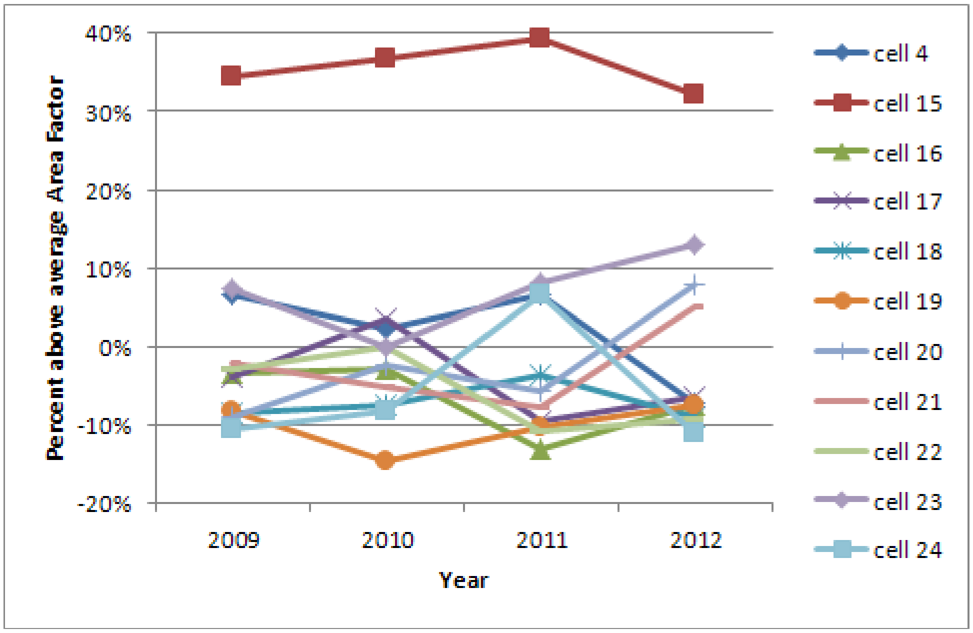

Figure 3.2. MnROAD Performance Categories Based on Area Factor (Drv. Lane- OWP)

Surface Characteristics

Noise

Sound intensity was measured using an on board sound intensity (OBSI) apparatus, which is a close proximity method (cpx). OBSI equipment consists of a Chevrolet sedan and eight intensity meters connected to a front end collector connected to a laptop computer. A rig system attaches the intensity meters to a standard reference test tire that is installed at the rear right (passenger) side of the vehicle. The unit is capable of measuring repeatable tire pavement interaction noise of the tire pavement contact patch at a speed of 60 miles an hour, thus measuring approximately 440 ft within 5 seconds (14).

The A-weighted frequency is a logarithmic scale used to mimic the human hearing spectrum (15). If *n* similar sources generate a noise level *i*, then the total noise level is given by

Equation 3. Consequently, if there are 2 sources with the same sound intensity, the cumulative intensity is thus 3 dBA higher than the individual intensity. This implies that a reduction of the sound intensity by 3 dBA is equivalent in effect to a traffic reduction to 50 % of original ADT (15).

$$dB(A)_t = 10\log[10^{dB(A)_1/10} + 10^{dB(A)_2/10} + \ldots + 10^{dB(A)_n/10}] \qquad \text{Equation 3}$$

Initial OBSI was collected in October 2008. The following sets of measurements bring the total to (11) eleven measurement sets made since construction.

- three sets of measurements made in 2009
- four in 2010
- three in 2011
- one in 2012

Figure 3.3 to Figure 3.5 show the variation of the A-weighted sound intensity of the driving and passing lanes of each individual study cells with time. Figure 3.6 and Figure 3.7 compare the A-weighted sound intensity of each study cell of the driving and passing lanes, respectively.

The initial seasonal effects seemed to influence OBSI measurement results more than construction type. In addition, the seasonal effects on the OBSI measurements appear to have an influence over all of the study cells; contrast this result to the ride values (Table 2.3), where few cells experienced dramatic seasonal variations. The data collected since November 2010 showed all cells holding the OBSI levels through several seasonal changes. Recent OBSI measurements showed most cells in the passing lane were performing at uniform levels just below the 4-year maximum OBSI levels. Driving lane cells showed more variability in OBSI data, but were all below the 4-year maximums.

Even though the FRAP cells had an initially higher OBSI reading, this was later surpassed by Cell 15 and others. This suggests that the presence of FRAP in the HMA mixture has less of an influence on the measured sound than other factors, such as pavement distress, ride and others. It must be stressed that the initial relative noisiness of the FRAP cells appears to have dissipated. Note that although MnDOT is currently investigating the use of quiet pavements at MnROAD, there currently is no noise standard for the construction of HMA pavements and MnDOT does not currently consider quiet pavements as an alternative to noise walls.

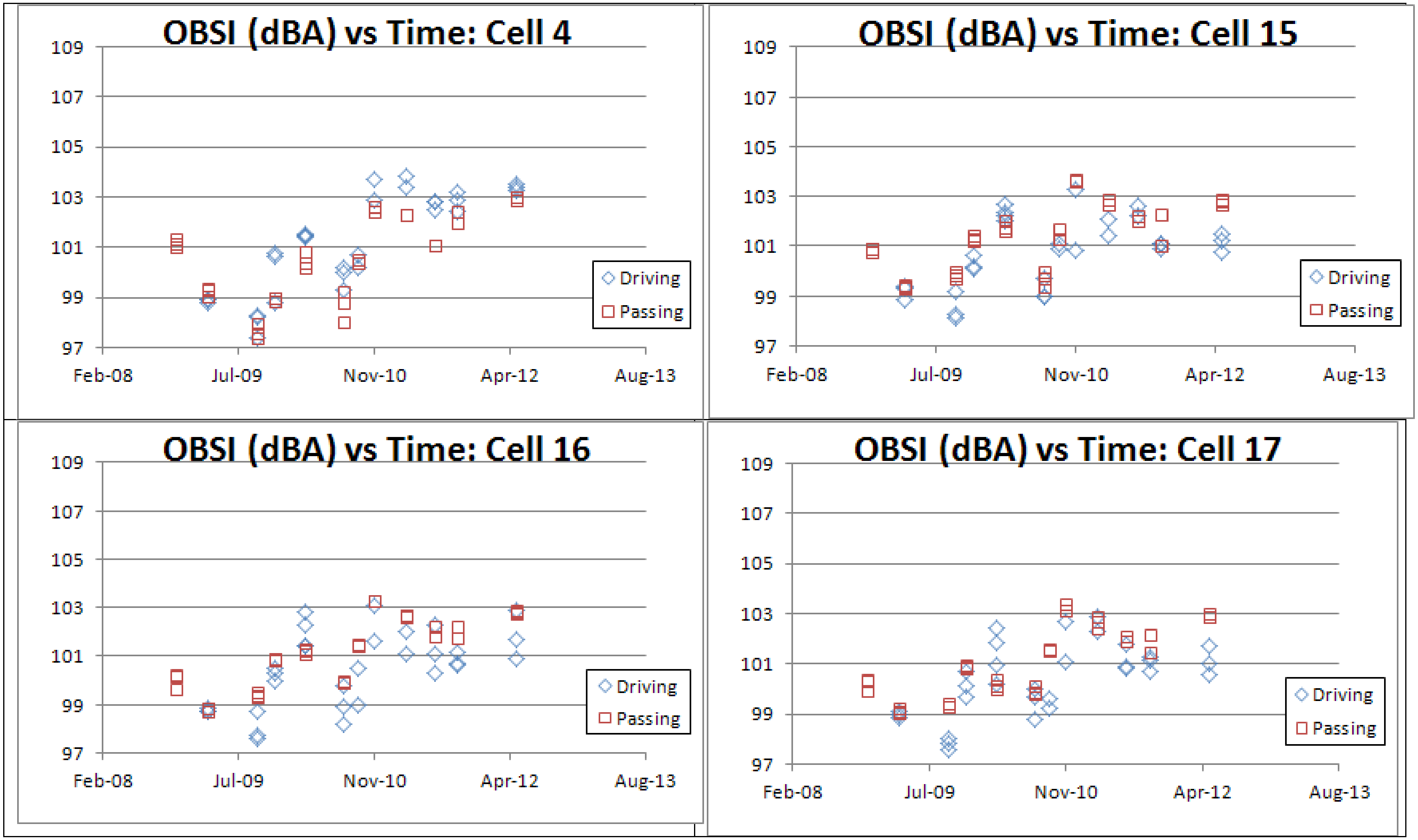

Figure 3.3. OBSI Results Cells 4 - 17

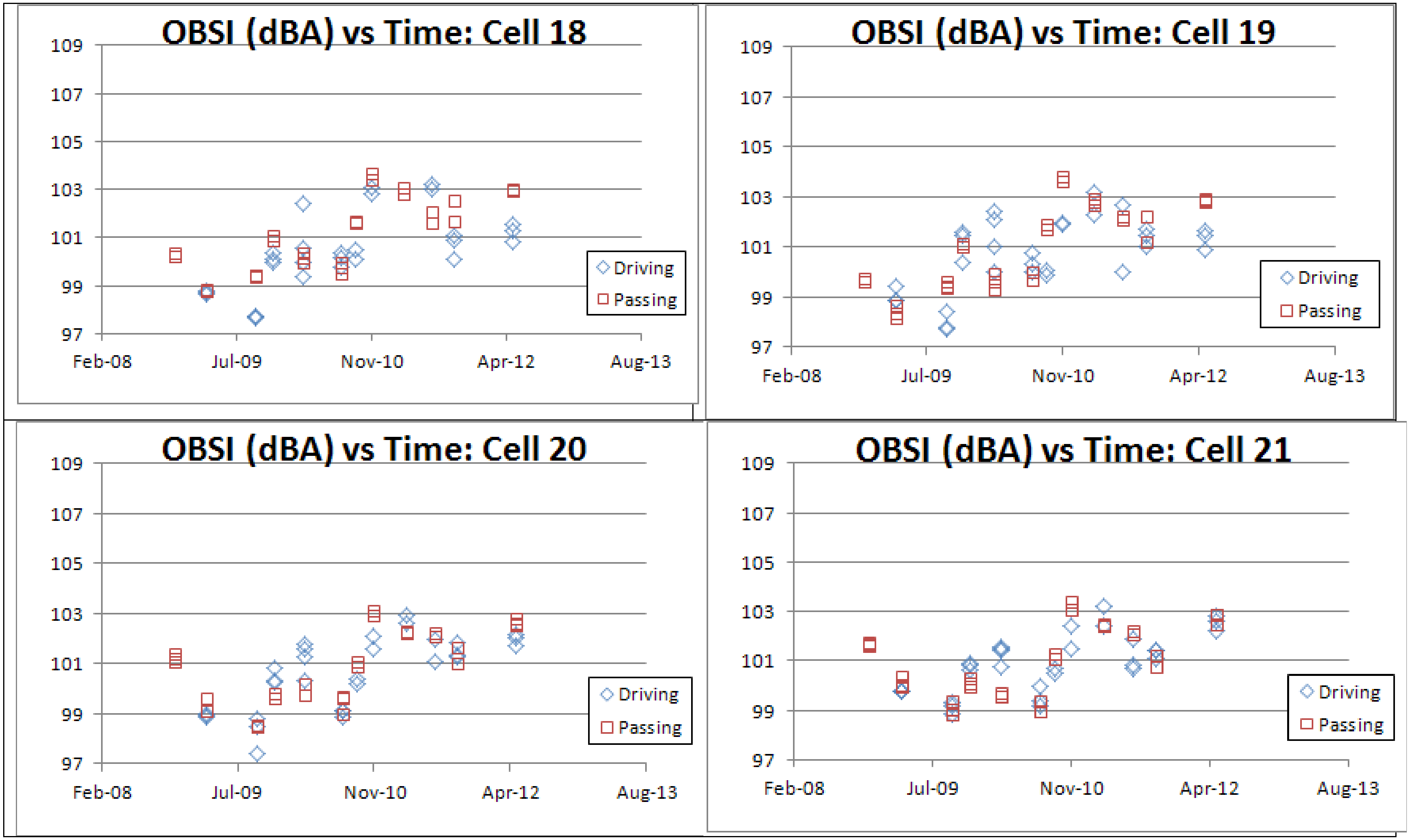

Figure 3.4. OBSI Results Cells 18 - 21

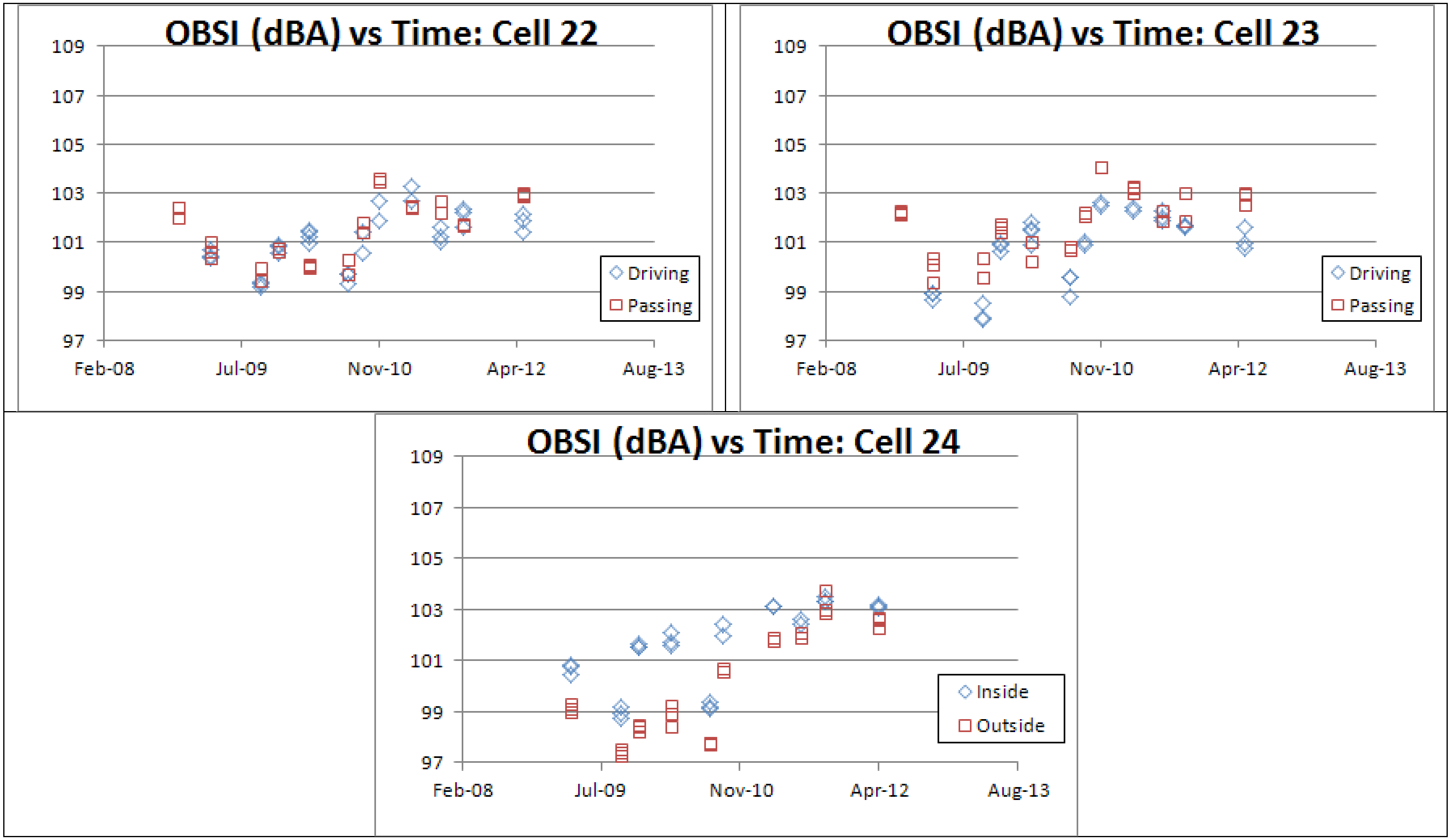

Figure 3.5. OBSI Results Cells 22 - 24

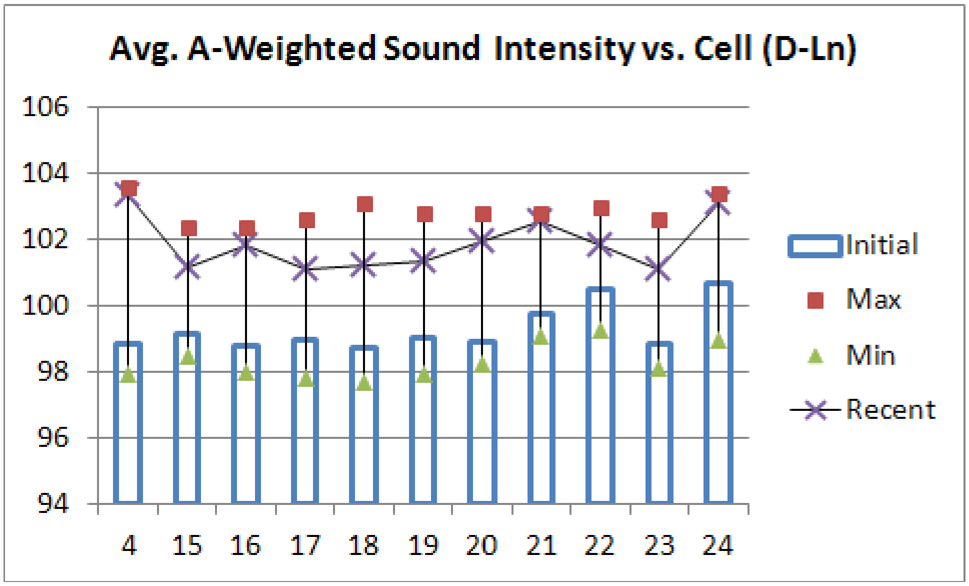

Figure 3.6. Avg. A-Weighted Sound Intensity (dBA) vs. Cell, Nov. 2008 – Apr. 2012

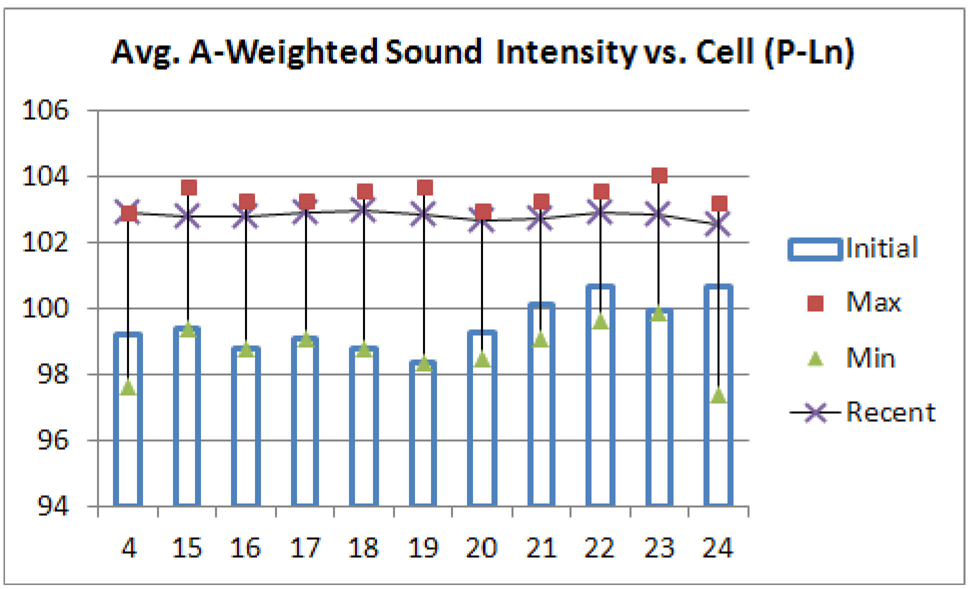

Figure 3.7. Avg. A-Weighted Sound Intensity (dBA) vs. Cell, Nov. 2008 – Apr. 2012

Friction

Tire-pavement friction was evaluated using a Dynatest Locked-Wheel Skid Trailer in accordance with ASTM E 247 (13). Friction numbers were measured when locking a ribbed test tire at a speed of 40 miles per hour (100% slip condition). The measured values are denoted as FN40 (Ribbed). Values obtained from the friction tests are intended for comparison with other pavements, or to chart the change with time, and are insufficient to determine vehicle stopping distances (13). Seven measurements of the study cells have been conducted since construction: October 2008, June and November 2009, September 2010, April and September 2011, and April 2012. Figure 3.8 and Figure 3.9 show the initial reading taken on October 2008, the most recent measurement, and corresponding maximum and minimum measurement values that occurred during the analysis period for the driving and passing lanes.

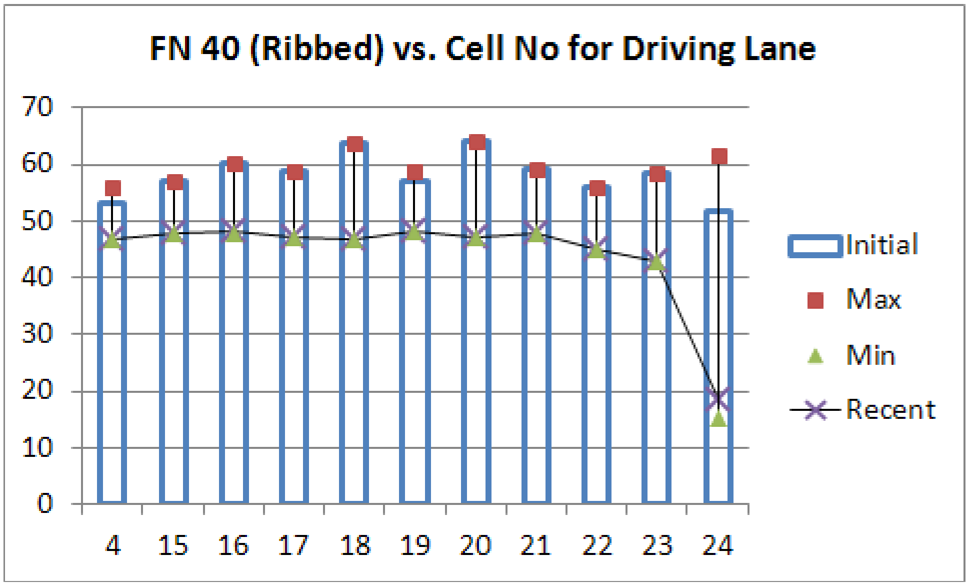

Figure 3.8. Avg. Friction (FN40Ribbed) vs. Cell (Drv-Ln), Oct. 2008 – Apr. 2012

In June 2009 the average MnROAD bituminous friction number was found to be 47.3. All study cells produced initial friction number readings at or above 40. The current and minimum measured values are all still well above 40, and closer to the 50's. Driving and passing lanes show similar performance at this time; performing at 1 and 4% above their average minimum FN40's during the study period. For this group of cells, the overall FN40 values have declined by 20.3% (mean) between October 2008 and September 2011 (18.1% median decline). The friction performance of the study cells appears to be relatively uniform, and the experimental variables of: FRAP, varying proportions of RAP, and grades of virgin asphalt binder, as well as the use of warm mix asphalt technology do not appear to influence the results significantly.

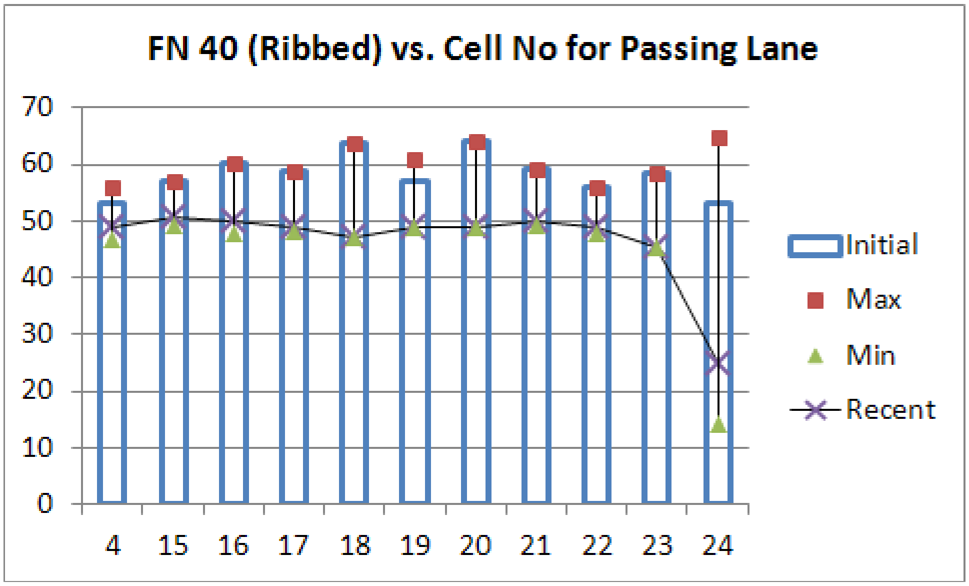

Figure 3.9. Avg. Friction (FN40Ribbed) vs. Cell (Pass-Ln), Oct. 2008 – Apr. 2012

Cell 24 is the only cell that has friction numbers of low quality. Initial friction was similar to the other cells in the study. Prior to measurements in 2010 and 2011, heavy fog seal applications of undiluted CRS-2p emulsion were applied to the outside and inside lanes of Cell 24 as part of a national pooled fund study on the effects of environmental aging on HMA pavements. Regarding Cell 24 only, the charts show that minimum values of FN40 were measured during 2010.

Summary of Early Monitoring and Testing

The study cells have been tested for structural and surface characteristics to assess whether or not the experimental variables of: FRAP, varying proportions of RAP, and grades of virgin asphalt binder, as well as the use of warm mix asphalt technology have a measureable influence on pavement performance. The performance indicators included: structural characterization using Falling Weight Deflectometer testing and the AREA Factor, as well as noise and friction measurements.

The FWD testing, and subsequent analysis using the AREA factor, revealed that all cells appear to initially behaving in a structurally similar manner. These relative relationships appear to have been maintained in the two years since construction. OBSI sound measurements indicated that, although the FRAP cells had an initially higher (noisier) value, this difference quickly dissipated and they are now behaving in a similar manner to other study cells. The seasonal effects of the OBSI measurements seem to influence the results more than any particular cell type. Recent OBSI measurements showed most cells in the passing lane were performing at uniform levels just below the 4-year maximum OBSI levels. Driving lane cells showed more variability in OBSI data, but were all below the 4-year maximums.

Currently one of the loudest study cells is Cell 15, which is also in the worst condition, in terms of ride and surface distress. Friction testing revealed that the experimental variables are not having a noticeable influence on the frictional characteristics of the pavements as the study cells are behaving relatively uniformly.

Currently, the experimental variables do not appear to have an observable effect on the structural, noise or frictional characteristics of the pavement. Currently the performance of the study cells cannot be explained by the experimental variables, however, this may change with time as cells receive more environmental and traffic loadings.

Chapter 4: Conclusions and Observations

Conclusions

Three FRAP and eight RAP test cells, incorporating experimental variables of: varying proportions of RAP/FRAP, grades of virgin asphalt binder, and use of warm mix asphalt technology were constructed in close proximity to each other, within a state of the art pavement research test facility. This report documented the four complete cycles of annual measurements, testing and observations, which included: visual distress surveys, ride, rutting, FWD, noise, and friction measurements. In general, the performance history of the study cells has been similar, and therefore it may be too early to draw any meaningful conclusions about variable-performance relationships. The current observations can generally be attributed to factors other than the experimental variables. The following are general observations and comparisons that can be made about pavement performance as measured by the different indices.

Visual Distress Survey

- 37/81 (46%) of the total underlying cracks reflected through to the surface of Cell 15.
- Cell 16 has two cracks, both of which occurred directly over a lysimeter.
- Cell 20 has 2 cracks.
- Cells 21 and 23 have developed low severity longitudinal cracks.
- None of the other cells have shown any visible signs of distress.

Ride

- Cells 4 and 15 were heavily influenced by seasonal variation (spring-thaw)
- Cells with similar construction histories currently have similar IRI deterioration rates. The ride decay of the cells within the recycled unbound base and FRAP/low temperature cracking groups appears to be very similar. Cell 15 has the highest decay value, followed by Cells 4, 17, and 23. Cells 20 – 22 and 24 appear to have experienced the smallest decline in IRI.

Rutting

- Rutting was measured, and no significant values, defined as excess of 0.5 in., were measured except for the case of Cell 18. Rutting statistics for Cell 18 show values for the median and maximum were equal to 0.28 and 0.64 in.

FWD – AREA Factor

- The study cells appear to have been constructed with similar structural characteristics, and have maintained the relative relationships with the fourth round of testing.
- After the Spring 2012 round of FWD testing, the average AREA factor had surpassed the initial value by approximately 5%.

Noise

- The FRAP Cells (21 and 22) had an initially higher OBSI reading; however Cell 15 has since surpassed the FRAP cells, which are behaving similar to the other study cells.
- All study cells appear to be affected by the seasonal variations in relatively the same way.
- Seasonal effects are the greatest influence on OBSI measurements.

Friction

- The study cells appear to have fairly uniform frictional characteristics with current FN 40 Ribbed near 50 for both driving and passing lanes.

- Cell 24 was fog sealed in 2010 and 2011, and FN 40 values were very low. Minimum values occurred in 2010.

References

1. B. Arseneau. “MnDOT’s Recycled Materials Philosophy”. Presentation at the RAM/SWAM Conference, October 22, 2009. http://swanachapters.org/Portals/7/Arseneau_Shingles.pdf, accessed November 1, 2010.
2. A. Johnson, Clyne, T. R., Worel, B. J. “2008 MnROAD Phase II Construction Report”. Minnesota Department of Transportation, June 2009.
3. E. Johnson. “Construction of Three Fractionated RAP and Eight RAP Test Cells at MnROAD”. MnROAD Study of Fractionated RAP, Task 2 Summary (Interim) Report, Minnesota Local Road Research Board Investigation 864, MPR-2(022), 2010.
4. Minnesota Department of Transportation, Standard Specifications for Construction, “2360: Plant Mixed Asphalt Pavement, Gyratory Design Specification, February 4, 2011”, http://www.dot.state.mn.us/materials/bituminousdocs/Specifications/2011/2360-2011__Final%202-4-2011.pdf, accessed November 17, 2011.
5. Minnesota Department of Transportation, Standard Specifications for Construction, “2360: Plant Mixed Asphalt Pavement, Gyratory Design Specification, February 1, 2010”, http://www.dot.state.mn.us/materials/bituminousdocs/Specifications/2010/2360/2360-2010_Spec.pdf, accessed November 4, 2010.
6. E. Johnson, Johnson, G., Dai, S., Linell, D., McGraw, J. and Watson, M. “Incorporation of Recycled Asphalt Shingles in Hot-Mixed Asphalt Pavements”, Report MN/RC 2010-08. Minnesota Department of Transportation, Saint Paul, MN, 2010.
7. J. Miller, Bellinger, W. “Distress Identification Manual for the Long-Term Pavement Performance Program (Fourth Revised Edition)”. Federal Highway Administration, FHWA-RD-03-031, June 2003.
8. D. S. Moore, and McCabe, G. P. *Introduction to the Practice of Statistics*, Fifth Edition. W. H. Freeman and Company, 2006, New York.
9. Janisch, D. “An Overview of MnDOT’s Pavement Condition Rating Procedures and Indices”. Minnesota Department of Transportation, Saint Paul, MN, May 2006.
10. M. Cole, Clyne, T. “MnROAD Cell 4 Forensic Investigation, Final Report”. Minnesota Department of Transportation, June 2010. http://www.mrr.dot.state.mn.us/research/pdf/2010MRRDOC011.pdf, accessed November 4, 2010
11. “Rutting”. http://pavementinteractive.org/index.php?title=Rutting, accessed November 4, 2010.
12. M. Turos, Moon, K., and Marasteanu, M. “Air Voids Testing for Mn/ROAD Cells”. Minnesota Department of Transportation, July 2010.
13. “Standard Test Method for Measuring Skid Resistance of Paved Surfaces Using a Full-Scale Tire,” ASTM Standard Practice E-274-06, IHS online ASTM Standards, American Society for Testing and Materials, West Conshohocken, PA, 2006.
14. Izevbekhai, B. “Report on Pavement Surface Characteristics Mini-Rodeo (MnDOT Test Data and Data Comparison)”. Minnesota Department of Transportation, Unpublished Report, 2008.

15. Izevbekhai, B. "Report of Pavement Surface Characteristics Mini Rodeo (MnDOT Test Data and Data Comparison)". Minnesota Department of Transportation, Project MPR 6-(012) and TPF 5-(134), July 2008.
16. M. Watson, Johnson, E. "Annual Monitoring and Performance Report for Years 1 and 2". MnROAD Study of Fractionated RAP, Task 3 and 5 Summary (Interim) Report, Minnesota Local Road Research Board Investigation 864, MPR-2(022), 2011.
17. E. Johnson. "Annual Monitoring and Performance Report for Year 3". MnROAD Study of Fractionated RAP, Task 6 Summary (Interim) Report, Minnesota Local Road Research Board Investigation 864, MPR-2(022), 2012.