

1 **ACOUSTIC EFFECTS ON PAVEMENT SMOOTHNESS PERCEPTION**

2 By

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15 **Figures 11 (X250) = 2750**

16 **Tables 1 (X250) = 250**

17 **Words = 4373**

18 **Total = 7373**

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## **ABSTRACT**

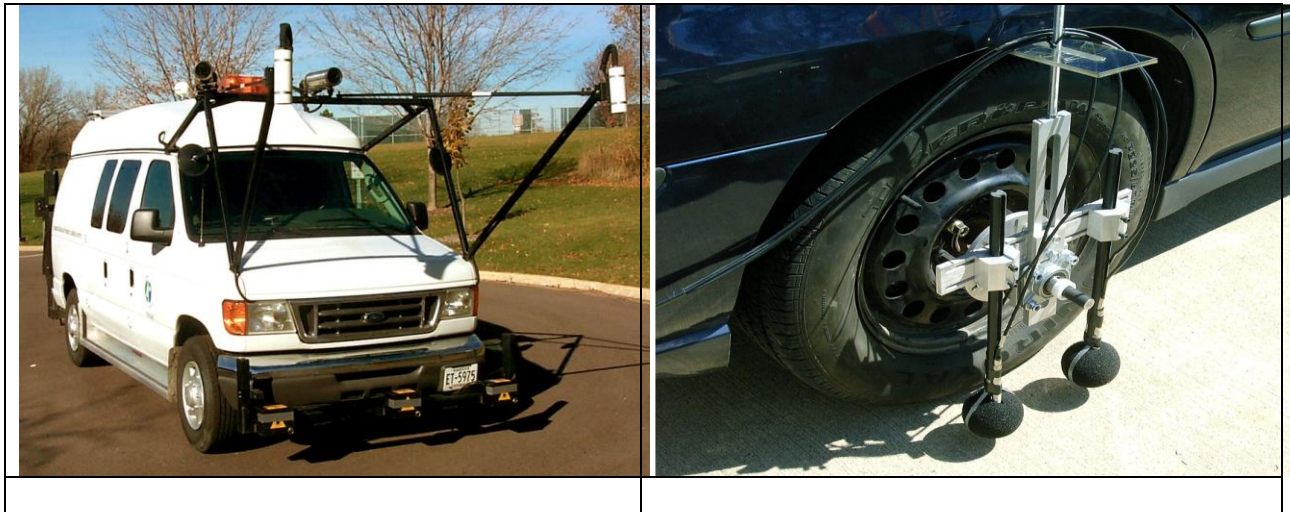
A study examined thirty one pavement test sections in the Minneapolis St Paul area to determine if tire pavement noise (OBSI) from the pavement surface affects perception of pavement smoothness (MPR). Forty six volunteers rode as passengers in 2010 Chevrolet Malibu sedans over the contiguous ½ mile long rigid or flexible pavement test sections scoring MPR. Results of MPR were compared to the International Roughness Index (IRI) measured with the digital inspection vehicle at the same time. The AASHTO TP 76-09 procedure for OBSI procedure for near field measurement was used to measure tire pavement noise. Using statistical analysis and tests, the MPR and OBSI were examined for correlation of the latter to anomalies in the former. OBSI did not seem to explain anomalies in MPR referenced from measured IRI. However, the sequencing of the test sections for the ride survey appeared to have influenced some of the ratings of some test sections. Moreover there was some evidence of correlation of IRI and MPR to OBSI.

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1 **INTRODUCTION**

2 The Minnesota Department of Transportation (Mn/DOT) is responsible for approximately  
 3 12,000 centerline miles of pavement surfaces. Each year, the pavement condition of the entire  
 4 trunk highway system is measured using a Pathway Services, Inc. Digital Inspection Vehicle  
 5 (DIV) that utilizes a total of five lasers and four digital cameras [1] (FIGURE 1).

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10 **FIGURE 1: Mn/DOT's Digital Pathways Van and OBSI Contraption**

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12 The DIV reads the longitudinal profile of the pavement while gathering information and  
 13 facilitating through data reduction, the assignment of frequency of occurrence and degree of  
 14 severity to faulting, rutting and the pavement roughness (International Roughness Index - IRI)  
 15 Cameras photograph the pavement surface to enhance determination of the severity and  
 16 frequency of various pavement surface distresses. This provides annual updates on the  
 17 VIDEOLOG, which is the statewide video file that facilitates a drive through the network by  
 18 proxy and remotely read IRI and pictures of the pavement surface. [1].

19

20 In Mn/DOT's 20-year Transportation Plan, Ride Quality Index (MPR) is used to determine the  
 21 smoothness of the pavement from the perspective of an average traveler [2. It is the current  
 22 Mn/DOT appellation of terminal serviceability rating also known as ride quality index (RQI). It  
 23 is not transcribed from IRI as that process would make it an actual index but is a raw value from

1 1 to 5 assigned to a pavement ride evaluation where 5 is a perfectly smooth ride. DIV measures  
 2 the IRI thus facilitating in this study an establishment of correlations between IRI and the  
 3 public's perceptions (MPR). Survey was last completed in 1997 by thirty two volunteers that  
 4 rated 120 different test sections. Each test section was a quarter of a mile long and had a range  
 5 of various roughness conditions and pavement types. The survey volunteers rated the quality of  
 6 pavement ride on a scale of zero to five (worst to best). These results were then tabulated for  
 7 each test section and correlated to the IRI values that were collected at the same time. Two  
 8 equations were then created to correlate IRI values (inches per mile) to the MPR for bituminous  
 9 (equation 1.1) and concrete surfaces (equation 1.2) [3].

10

$$(Bituminous) \quad RQI = 5.6972 - 0.264\sqrt{IRI} \quad (Equation 1.1)$$

$$(Concrete) \quad RQI = 6.6341 - 0.353\sqrt{IRI} \quad (Equation 1.2)$$

11  
 12 The pavement surfaces around the trunk highway system are thus rated according to these  
 13 equations. These correlations in true reflection of public perception will only change the public's  
 14 appreciation of smooth and rough roads changes [3].

## 16 Study Objective

17 This study examined thirty one test sections in the Minneapolis St Paul area to determine if the  
 18 noise (OBSI) from the pavement surface affects perception of pavement smoothness. By  
 19 examining test sections with anomalous IRI- MPR correlation, study investigates if OBSI  
 20 explains anomaly in MPR scoring.

## 22 SURFACE VARIABLES

### 23 Pavement Rating

24 Decisions for repair or replacements are usually contingent upon ride performance and surface  
 25 ratings. The pavement roughness and digital image data for the entire trunk highway system is  
 26 collected yearly with the Pathway Services, Inc. Digital Inspection Vehicle (DIV) that utilizes a  
 27 total of five lasers, and four digital cameras. The data and images collected are then used to  
 28 determine the Surface Rating, Pavement Quality Index and the Remaining Service Life [1].

1

**2 Ride Quality Index (MPR)**

3 The MPR is a measure of the pavement smoothness using a zero (rough) to five (smooth) scale.  
4 Most new pavements have an initial MPR value of 4.2 and have a terminal MPR of 2.5. The  
5 MPR represents the rating that a typical road user would give to the pavement's smoothness as  
6 felt while traveling on the pavement. The MPR can be calculated by data measured from the  
7 DIV and correlated using previous ride surveys. The measurement collected is called the  
8 International Roughness Index (IRI) and it estimates the amount of vertical movement a standard  
9 vehicle would experience if driven on the pavement [4]. IRI is a longitudinal profile in a  
10 wheelpath and is a ratio of the vehicle's accumulated suspension motion divided by the distance  
11 that was traveled [5].

12

**13 Surface Rating (SR)**

14 The pavement distresses visible on the pavement surface accounts for the SR and is rated on a  
15 scale of zero (impassible) to four (no distresses). Distresses such as cracks, patches and ruts are  
16 indicative of pavement deterioration. These visible defects are quantified using the SR and can  
17 be used to determine if future rehabilitation or maintenance is needed. The SR is determined by  
18 identifying the surface defects from the images of the pavement collected by the DIV and  
19 combined with weighing factors depending on the type of distress or severity. A pavement with  
20 no defects has a rating of 4.0 and one that needs rehabilitation or maintenance is around 2.0 [1].

21

**22 Pavement Quality Index (PQI)**

23 The PQI accounts for the pavement smoothness and the amount of surface distress (equation  
24 2.1). It gives an index value for the overall condition of the pavement by finding the geometric  
25 mean [1]. The PQI is on a scale of zero (impassible) to 4.5 (excellent condition).

$$PQI = \sqrt{(RQI)(SR)} \quad (\text{Equation 2.1})$$

26

**27 On-Board Sound Intensity (OBSI)**

28 Since it is hypothesized that noise may bias the perception for the ride quality, OBSI  
29 measurements were needed to determine tire-pavement noise. OBSI records the tire-pavement

1 interaction noise at 60 miles per hour with sophisticated microphones installed near the contact  
2 patch (FIGURE 1) [6].

3 OBSI testing is based on the interim protocol adopted by AASHTO in 2009 [7]. For the  
4 analysis, an A-weighted logarithm scale was utilized to mimic the human hearing spectrum [8].  
5 The sound intensity ( $SI$ ) is the rate of acoustic energy transmission per unit area ( $W/m^2$ ). Then,  
6 the sound intensity level ( $SIL$ ) is the logarithmic measure of the sound intensity in comparison to  
7 a reference level ( $SI_0$ ), which is measured in decibels (dB) (equation 2.2). The reference level is  
8 the sound intensity at the threshold of human hearing ( $10^{-12} W/m^2$ ).

$$SIL = 10 \log_{10} \left[ \frac{SI}{SI_0} \right] \quad (\text{Equation 2.2})$$

9  
10 As a result, the OBSI is calculated by using the sound intensity level equation and totaling the  
11 results from the 12 different sound intensity values found (equation 2.3).

$$OBSI = 10 \log_{10} \left[ 10^{(SIL_1/10)} + 10^{(SIL_2/10)} + \dots + 10^{(SIL_{12}/10)} \right] \quad (\text{Equation 2.3})$$

12  
13 Therefore, an A-weighted equation was expatiated where  $i$  represents the 12 third octave  
14 frequencies that are 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, and 5000  
15 hertz (equation 2.4).

$$OBSI = 10 \log_{10} \left[ \sum_{i=1}^n 10^{(SI_i/10)} \right] \quad (\text{Equation 2.4})$$

16  
17 Mn/DOT's equipment consists of a non-dedicated vehicle (2004 Chevrolet Impala) and four  
18 microphones connected via four communication cables to a Brüel and Kjær front-end collector  
19 routed to a laptop computer. A Standard Reference Test Tire (SRTT – ASTM F 2493) [9] with a  
20 mounted circular plate is used on the rear right side of the vehicle to stabilize the intensity meters  
21 during testing. The noise generated from the tire-pavement interaction is measured for five  
22 seconds while the vehicle is traveling at a constant speed of 60 miles per hour, thus averaging the  
23 OBSI over a 440 foot section.

24  
25 The implication of an OBSI difference in terms of actual percentage reduction in sound level  
26 deserves explanation. A 3-dBA reduction is tantamount to approximately 50 percent loss of

1 sound intensity from a uniform source. If  $OBSI_{(1)} - OBSI_{(2)} = n$  and the respective sound  
 2 intensities are in Watts /m<sup>2</sup> are  $I_{(1)}$  and  $I_{(2)}$  respectively then

3  $10 \log \left( \frac{I_2}{I_0} \right) - 10 \log \left( \frac{I_1}{I_0} \right) = n$  where  $I_0$  is the sound intensity at the threshold of human hearing

4 Thus  $\left( \frac{I_2}{I_1} \right) = 10^{\frac{n}{10}}$ .

5 For instance where  $n=3$ , then ratio of actual sound intensity ratio is 2. Similarly,  $\left( \frac{I_2}{I_1} \right)$  is 4 when  $n$   
 6 is 6 dB.

7

## 8 **EXPERIMENTAL DESIGN**

### 9 **Description of Test Sections**

10 The test loop began from Minnesota Highway 36 just east of White Bear Avenue (heading east).  
 11 The loop traveled on Interstate 694, Interstate 494, Lake Road, Washington County State Aid  
 12 Highway 19, County State Aid 20, Minnesota Highway 95 and Interstate 94. It test loop ended  
 13 on Interstate 94 (heading west) near the US Highway 61 exit. A map to illustrate the loop is  
 14 shown below (FIGURE 2).

15 Thirty one test sections were surveyed. Each test section was half of a mile long, varied from  
 16 concrete to bituminous, had different distresses present and the speed limits varied. Also, some  
 17 of the test sections were on the interstate highway and others were on county roads. Each of the  
 18 test sections were given a landmark at the start of the test section and the starting odometer from  
 19 the start of the route was also used (TABLE 1). Contiguity of the test sections minimized  
 20 unnecessary travel during the survey.

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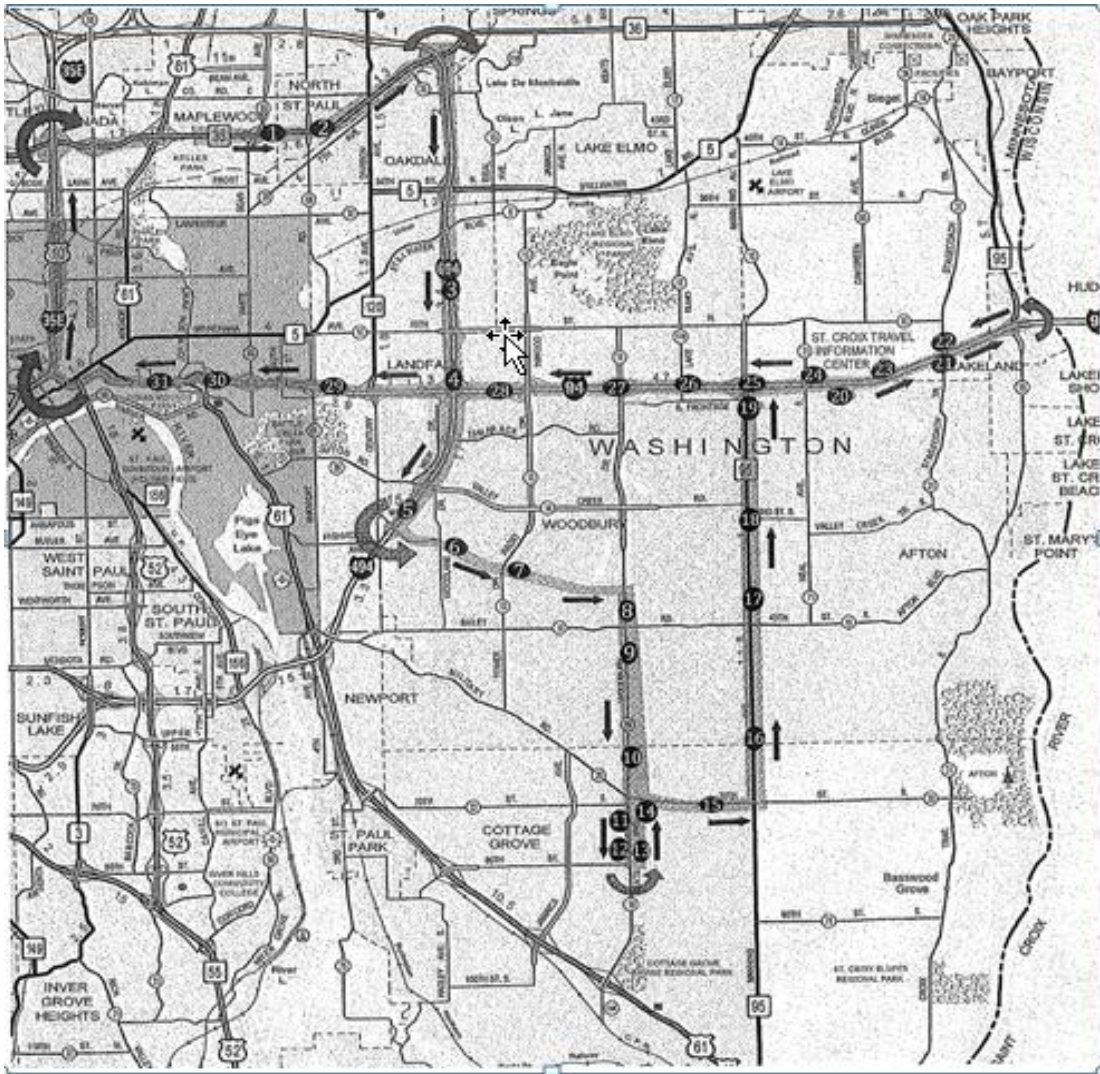


FIGURE 2 – Test Section Map

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**2010 Ride Survey**

Of the participants, 24 were male and 22 were female and also had a varying distribution in occupations and ages. The participants in the study determined a roughness rating based on how the ride felt over the test section. They rated it on a scale of 1 (impassable) to 10 (perfect). Since the MPR is on a scale of 0 to 5, the ratings and MPR were considered to be on a linear scale. Thus the ratings were halved to determine the MPR values of the test sections. Participants were chosen to minimize biases in education, age and gender.



1 **IRI Measurements**

2 Directly following the rating vehicles, the DIV took IRI measurements for comparison. Since  
3 the rating vehicles did four different trips with different people, the DIV had four different runs  
4 with data. The data was averaged and the MPR was calculated using the equations from the  
5 1997 ride survey (Table 1). This information was then compared with the MPR values that the  
6 2010 ride survey determined.

7  
8 **OBSI Measurements**

9 OBSI measurements were performed after the survey rated the test sections, but the  
10 month/season was still the same. In each test section, three continuously tested OBSI  
11 measurements were taken. OBSI was measured following the same sequence as the rating  
12 survey vehicles. OBSI completed the loop twice at 60 miles per hour, meaning a total of six  
13 measurements per test section. These measurements were then averaged to give the OBSI value  
14 for the various test sections.

15  
16 In addition to normal OBSI testing, the testing was also performed at the speed limit for the  
17 various roads. It was hypothesized that OBSI numbers would be more germane to the actual  
18 noise that the public was hearing because the tire-pavement noise is affected by the speed of the  
19 vehicle [10]. For this testing, a total of three measurements were created and they were averaged  
20 for each test section.

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2 **TABLE 1: Results of Ride and Noise Survey.**

Section ID	User Rating	Mean MPR	Pavt Type	Mean IRI	Mean RN	Mean 1997 MPR	OBSI Mean (Runs 1 & 2)	OBSI Mean Run 3	Test Speed for Run 3 (mph)
1	6.7	3.4	BIT	62.15	3.87	3.6	102.9	102.1	55
2	8.5	4.3	BIT	44.03	4.34	3.9	102.3	101.6	55
3	7.8	3.9	CON	44.07	4.10	4.3	103.3	103.2	60
4	8	4.0	BIT	57.73	4.12	3.7	103.9	104.1	60
5	8.1	4.1	CON	31.60	4.45	4.7	103.7	103.9	60
6	7	3.5	BIT	158.89	3.31	2.4	103.7	96.0	35
7	4.7	2.4	BIT	145.26	2.28	2.5	102.8	97.2	45
8	4.3	2.2	BIT	196.30	1.54	2.0	106.4	105.4	55
9	5.2	2.6	BIT	164.60	1.98	2.3	106.0	105.2	55
10	6	3.0	BIT	108.34	2.35	2.9	105.8	105.2	55
11	6.1	3.1	BIT	118.41	2.69	2.8	105.6	105.2	55
12	5.2	2.6	BIT	147.25	2.15	2.5	105.4	105.4	55
13	4.9	2.5	BIT	155.88	2.15	2.4	106.0	105.0	55
14	5.6	2.8	BIT	130.07	2.36	2.7	105.9	104.9	55
15	7.8	3.9	BIT	65.40	3.98	3.6	102.1	101.3	55
16	7.7	3.9	BIT	63.64	4.14	3.6	103.1	102.6	55
17	6.4	3.2	BIT	87.33	3.40	3.2	103.7	103.3	55
18	6.7	3.4	BIT	82.00	3.42	3.3	103.2	103.0	55
19	5.8	2.9	BIT	91.08	1.96	3.2	103.9	103.8	55
20	7.2	3.6	CON	52.19	3.53	4.1	104.9	106.4	65
21	7.3	3.7	CON	51.73	3.84	4.1	105.0	106.6	65
22	6	3.0	CON	60.62	3.35	3.9	105.6	106.7	65
23	6.5	3.3	CON	60.10	3.67	3.9	105.6	106.9	65
24	6.6	3.3	CON	61.79	3.61	3.9	106.0	106.9	65
25	6.2	3.1	CON	62.32	3.72	3.9	105.9	107.1	65
26	5.9	3.0	CON	62.98	3.63	3.8	105.9	107.1	65
27	6	3.0	CON	69.24	3.38	3.7	105.7	106.8	65
28	6.6	3.3	CON	103.30	3.40	3.0	108.6	110.1	65
29	6.8	3.4	BIT	70.30	3.57	3.5	104.4	103.3	55
30	4.2	2.1	CON	170.51	2.53	2.0	107.4	98.5	30*
31	5.2	2.6	CON	146.66	2.86	2.3	107.2	101.1	30*

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\*Tested below speed limit due to excessive traffic

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### **ANALYSIS OF DATA**

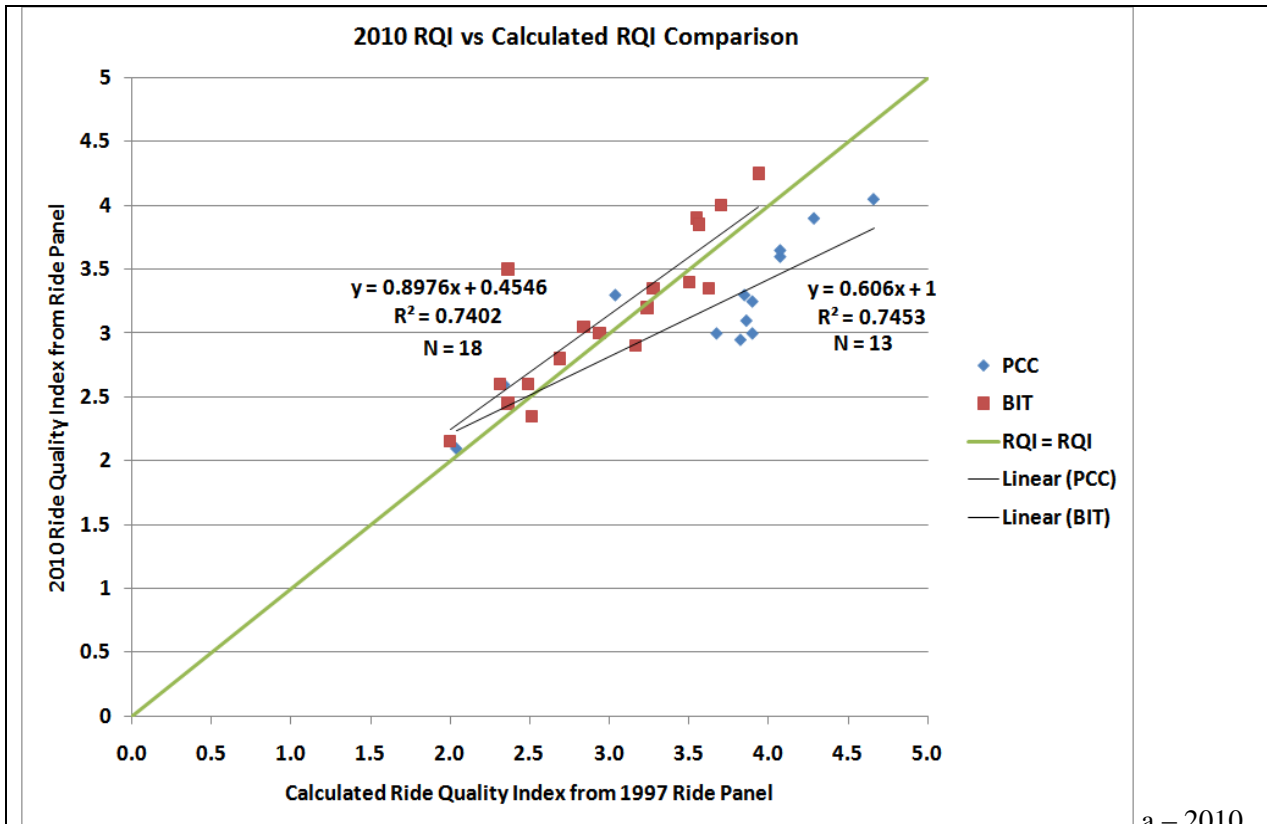
To analyze the data and ascertain if OBSI explains anomalies in IRI MPR correlations, the following analytical steps were performed:

- Curve fitting and identification of outliers
- Analysis of Anomalous Data Points
- Sequence examination

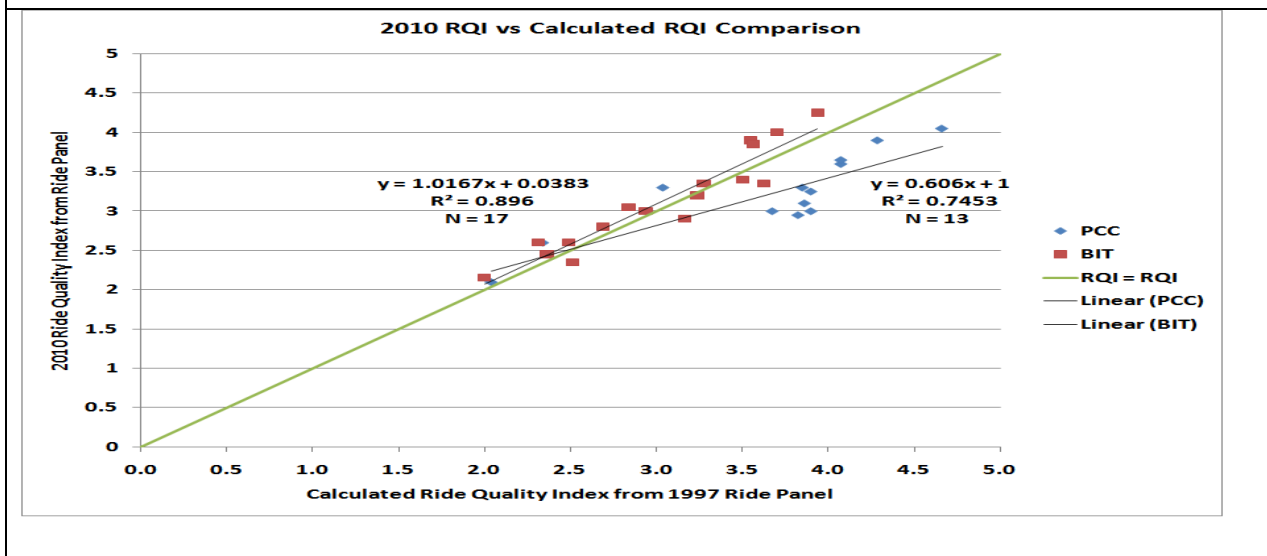
The rating values and the MPR values that the survey determined from the trip around the test sections was determined based on the averages from all of the participants (TABLE 1). The average IRI values from the DIV and the calculated MPR values and the noise measurements were tabulated for the two types of runs that were completed are shown in TABLE1. RN was also obtained from the DIV.

#### **Curve Fitting and Identification of Outliers**

This comparison determines how well the 1997 ride survey's MPR equations still relate to the smoothness based on current (2010) test. The 2010 MPR values determined from the ride survey should correspond directly to the MPR values that were calculated from the DIV-generated 2007 interpolations (FIGURE 3).



a) MPR Calculated Vs Measured

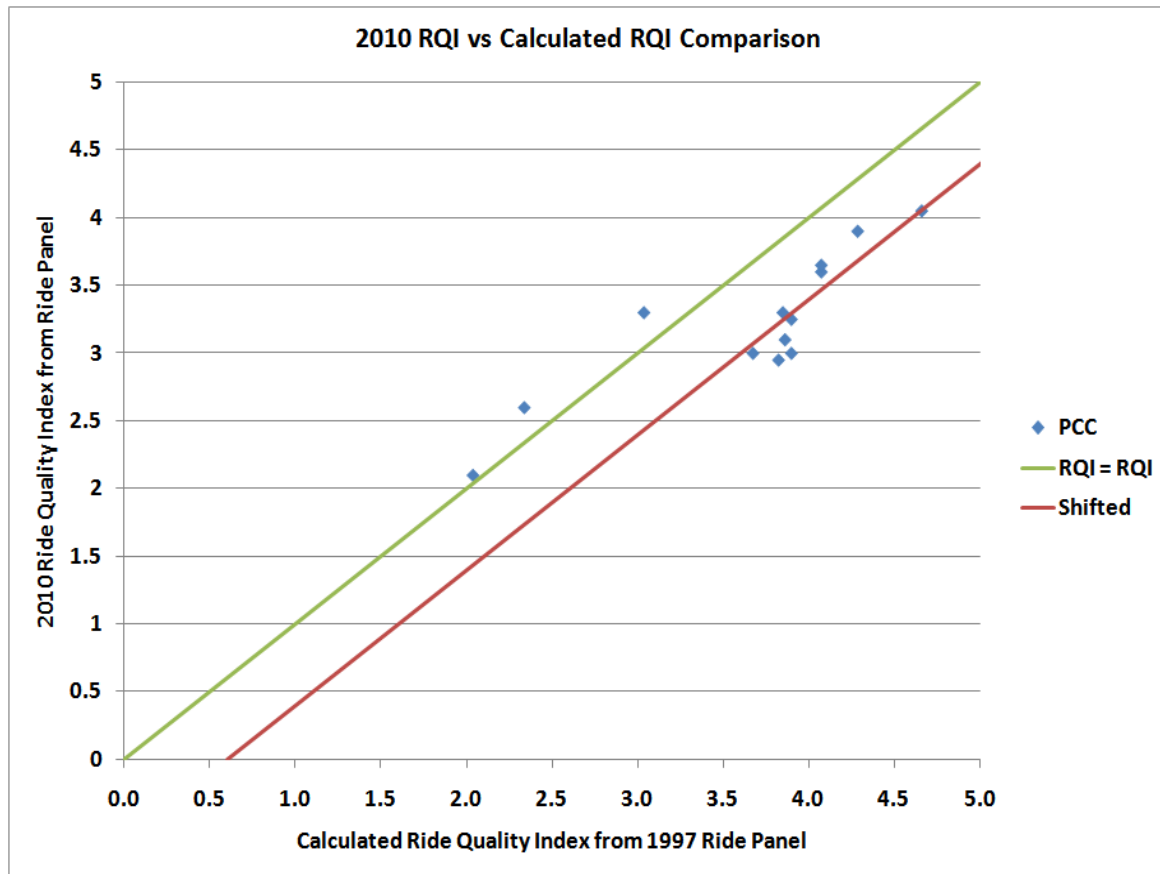


b –MPR Measured Vs. MPR Computed from 1007 Survey

1 **FIGURE 3: Measured Vs Computed Ride Quality Index**

1 As shown in FIGURE 3 a gross outlier was observed in section 6 (Lake Road) Analysis of data  
 2 without the outlier showed a much better fit (FIGURE 3) for the flexible pavements. The rigid  
 3 pavement test sections are consistently “underrated” and only three of the thirteen concrete test  
 4 sections had a similar rating to the MPR. The underrated test sections appear to have a similar  
 5 slope to the ideal line (FIGURE 4).

6



7

8 **FIGURE 4 - PSI and MPR Relationship with Shifted Intended PSI/MPR Line**

9 This shift in perception implies that based on the 1997 rating compared to 2010 rating, there has  
 10 been a change in perspective as to how concrete pavements ride or should ride. This perspective  
 11 did not seem to be affected by age but across the board, tolerance for poor ride in concrete  
 12 pavements appeared to have decreased. This can be attributed in part to improved pavement  
 13 standards including 60 year designs, better load transfer mechanisms (FIGURE 4), improved mix  
 14 designs (well graded aggregate, low water/ cement ratio) and high pozzolan substitution, and

1 other improved practices to which people are now accustomed. Current incentive specification  
2 has also favored a higher standard of paving,



a) – Use of Stainless Steel Dowel Bars in Increase Load Transfer Efficiency



b) – Use of “Ski” During Asphalt Paving to Increase Smoothness of Ride

3 **FIGURE 5: Efforts to Improve Ride Quality during Paving**

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5 In asphalt pavements efforts have been made over the last 14 years to improve ride by the use of  
6 sonic devices including the “ski” (FIGURE 5b) that senses the surface just before paving and



1 minimizes local amplitudes that would otherwise cause poor ride. However, improvement  
 2 between 1997 and 2010 was not observed by the raters.  
 3 By comparing the 2010 MPR equations with the ones from 1997, it is possible to ascertain if  
 4 public's perception on pavement smoothness has changed. Such comparison will accentuate  
 5 anomalies from any of the test sections that affect the correlation between IRI and OBSI  
 6 particularly if the OBSI is unusually influential. From the equations from the 1997 ride survey,  
 7 the form of the equation will be maintained in a certain form (equation 5.1) in which the  
 8 Mn/DOT pavement management unit has established indices from ratings. In the equation,  $k_1$   
 9 and  $k_2$  are constants that will be solved for to make the curve fit the best.

$$RQI = k_1 - k_2\sqrt{IRI} \quad (\text{Equation 5.1})$$

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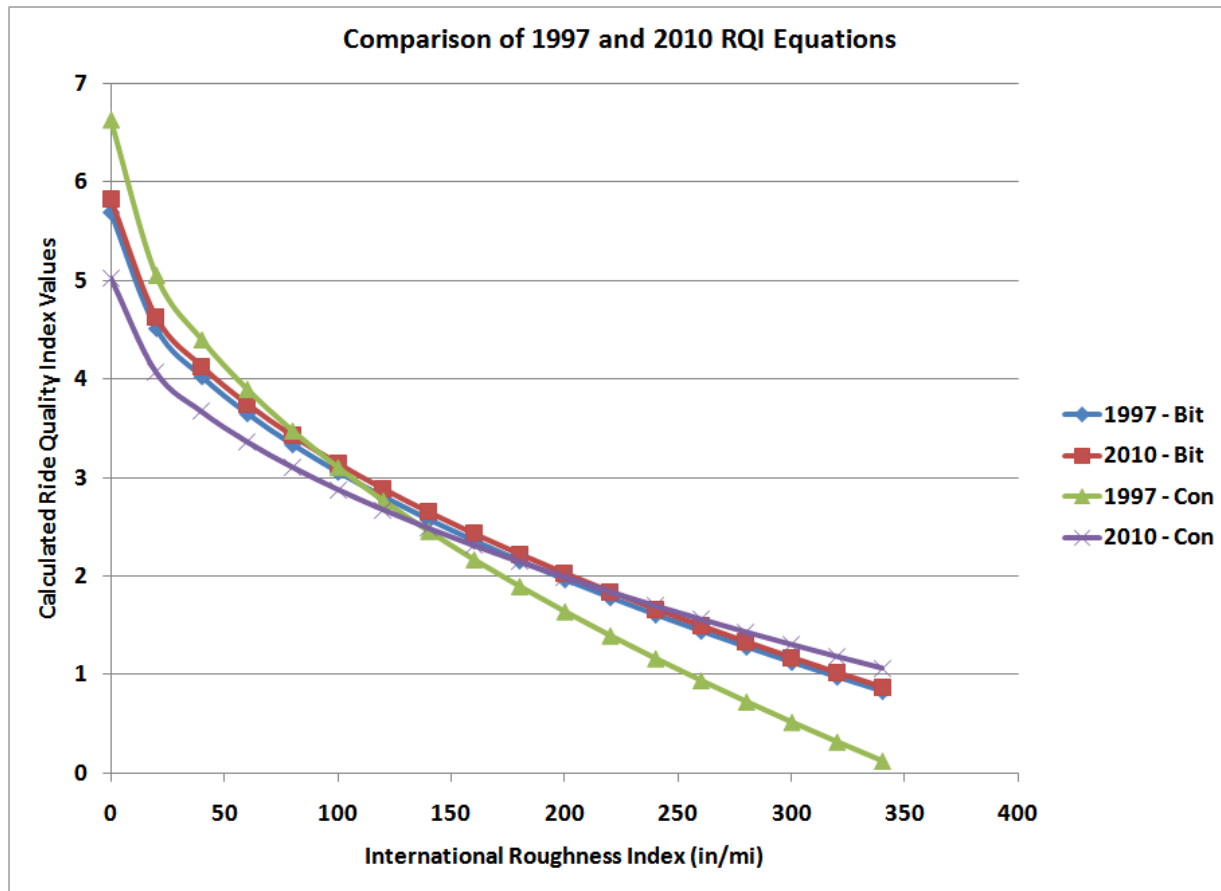
11 The calculated MPR from equation 5.1 was compared to the MPR values that the ride survey  
 12 determined and the sum of the squared residuals was evaluated and minimized. The MPR  
 13 equations for bituminous and concrete pavement structures was thus determined (equations 5.2  
 14 and 5.3, respectively) using curve fitting techniques.

$$(\text{Bituminous}) \quad RQI = 5.8306 - 0.269\sqrt{IRI} \quad (\text{Equation 5.2})$$

$$(\text{Concrete}) \quad RQI = 5.0278 - 0.215\sqrt{IRI} \quad (\text{Equation 5.3})$$

15

16 The 1997 MPR equations were then compared with the 2010 MPR equations (FIGURE 6).

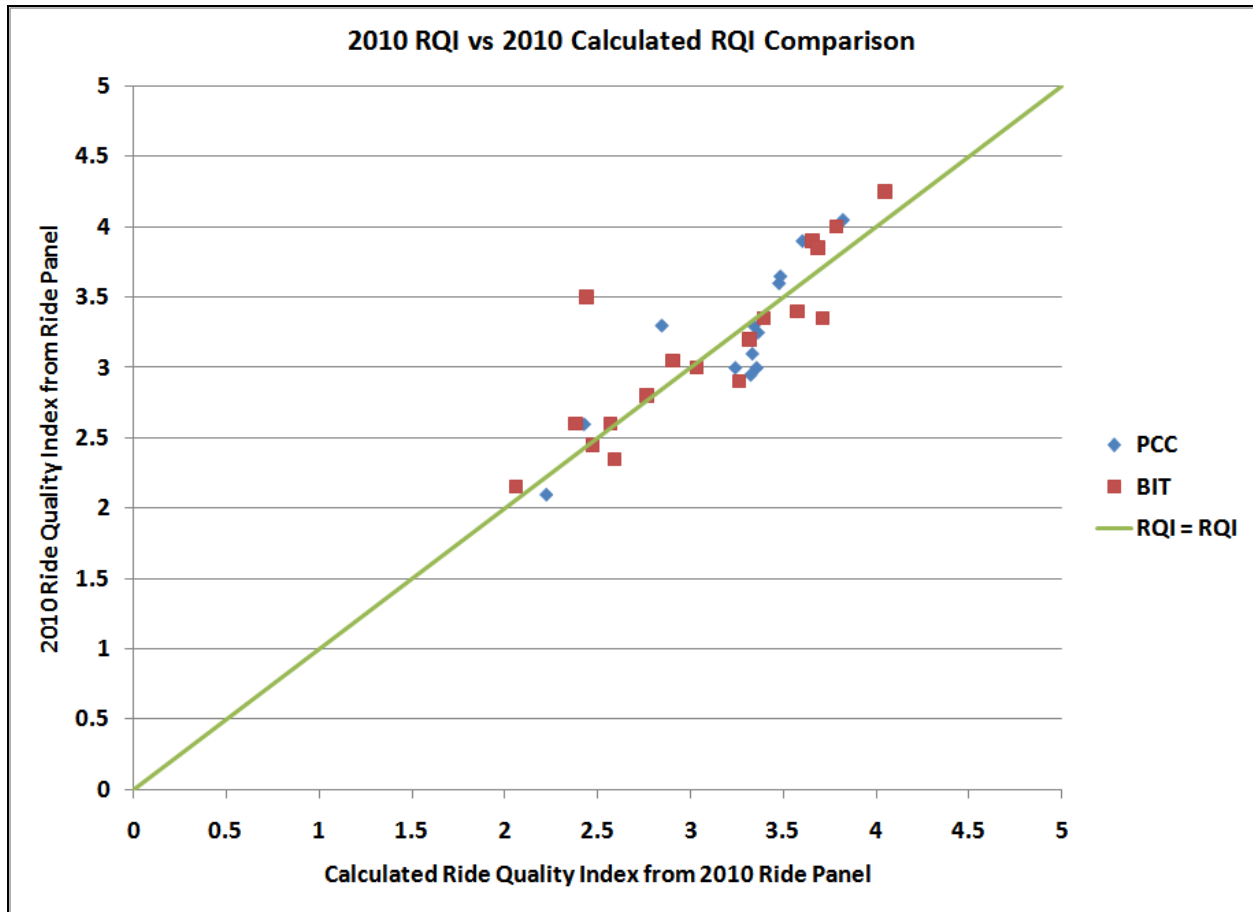


**FIGURE 6 – MPR Equations Comparison**

That chart shows that the public's perception toward the bituminous pavements has not changed, but it seemed to have changed towards concrete pavement surface. The 2010 MPR values favor the middle ratings more than the higher or lower numbers, but the lines cross at approximately when the MPR equals 2.5. This line for the 2010 MPR shows that the public is a little more forgiving of rougher concrete pavement than in the past.

#### *Analysis of New MPR Equations with Test Sections*

Using the new 2010 MPR equations, the public's perception on the MPR was graphed and the correlation between the two was compared (FIGURE 5.7).



1  
2 **FIGURE 7 – Measured MPR and Calculated MPR Relationship**  
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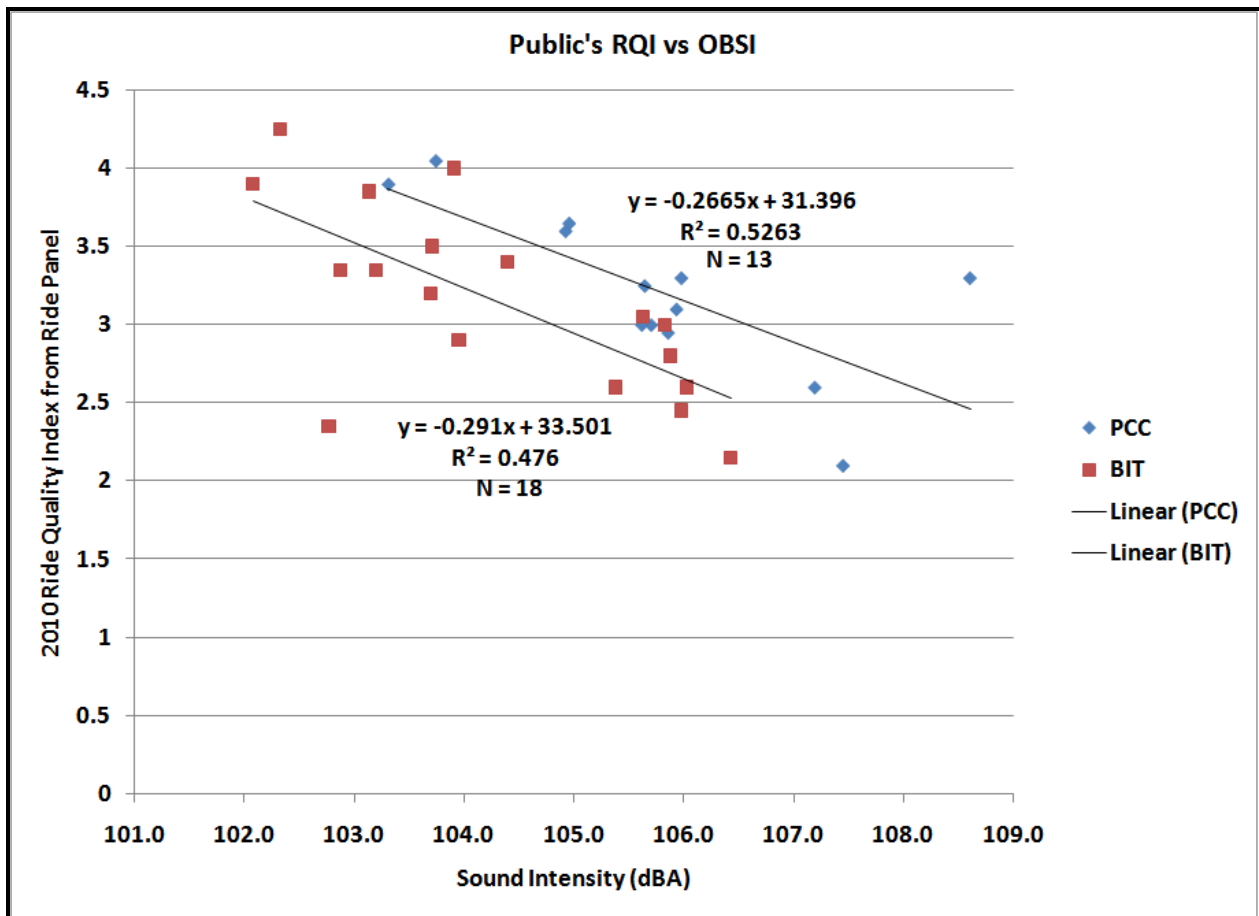
4 As shown in FIGURE 7, both the bituminous and concrete test sections follow the intended path.  
5 Test section 6 was once again an outlier on this graph. The data was well scattered along the  
6 ideal line of the MPR values. To determine statistical significance, of the MPR values from the  
7 ride survey P-values were determined.

8 P-value is defined as the evidence against the null hypothesis. Typically the null hypothesis  
9 proposes that there is no correlation between 2 variables. The alternate hypothesis states that  
10 there is a correlation between two variables that one is at least associative to the other. The P-  
11 value is a measure of the likelihood of encountering a type 1 error which is said to occur when  
12 the null hypothesis is true and the research shows it to be false. This is a false alarm. A type 2  
13 error occurs if the alternate hypothesis is true and the data or research fails to reject the null  
14 hypothesis. This is a failed alarm. Other statistics include statistical power which is based on the  
15 confidence level; a degree of certainty required that is based on  $\beta$  the likelihood of a type 2 error

1 and the size of the experiment or sample space. A rejection of the null hypothesis can be done  
 2 unequivocally. However, the alternative is a failure to reject the null hypothesis which is not the  
 3 same as acceptance of the alternate hypothesis.

4 The non-Bayesian field of statistics utilizes all available information or data and draws a  
 5 conclusion. The Bayesian approach builds an inference on existing or prior data. Subsequent data  
 6 serves as added information. In Bayesian statistics, a type 1 error is one that looks at information  
 7 that should not substantially change one's prior estimate of probability, but does. A type two  
 8 error is that one looks at information which should change one's estimate, but does not.

9 P-Value for 1997 – BIT and 1997 - PCC were 4.65E-06 and 0.000144 respectively. P-value for  
 10 2010 – BIT and 2010 - PCC were 4.41E-06 and 0.000129 respectively. Since all of the P-values  
 11 are below 0.05, it fulfils 95 percent confidence level that the data between the ride survey and the  
 12 various MPR equations are statistically similar.



13

14

**FIGURE 8 – MPR and OBSI Relationship**

### 1 **Examination of Individual Data Points of Anomalous IRI-OBSI Negative Correlation**

2 It is not known if acoustic perception of tire pavement noise could bias some raters. If it did, it  
3 could partly explain why the concrete test sections were rated differently in 2010 from 1997.

4 The tire-pavement interaction noise was measured using OBSI and this was compared with the  
5 MPR values from the public (FIGURE 8). The trends for the bituminous and concrete test  
6 sections are similar (FIGURE 8). As the pavement gets noisier, the MPR decreases. To  
7 determine if the ratings of the pavement smoothness was biased by on the tire-pavement  
8 interaction noise, they were graphed together to determine if a trend existed (FIGURE 9).

9 If pavements that ride poorly are likely to be noisy, the OBSI and MPR lines should have a  
10 similar pattern as it moves from test section to test section. For the true OBSI values, the pattern  
11 is similar to that of the MPR for about half of the test sections. Furthermore in the case of the  
12 noise values taken at the speed limit, a little less than half the data follows the same pattern as the  
13 MPR values. From these charts, it was still unclear if the noise biased the ratings. It was then  
14 deemed necessary to plot the residuals from the new MPR equations against the sound intensity  
15 values and determine if there was a correlation between the residuals and OBSI. The bituminous  
16 chart and the concrete chart are shown in FIGURE 9a and b respectively.

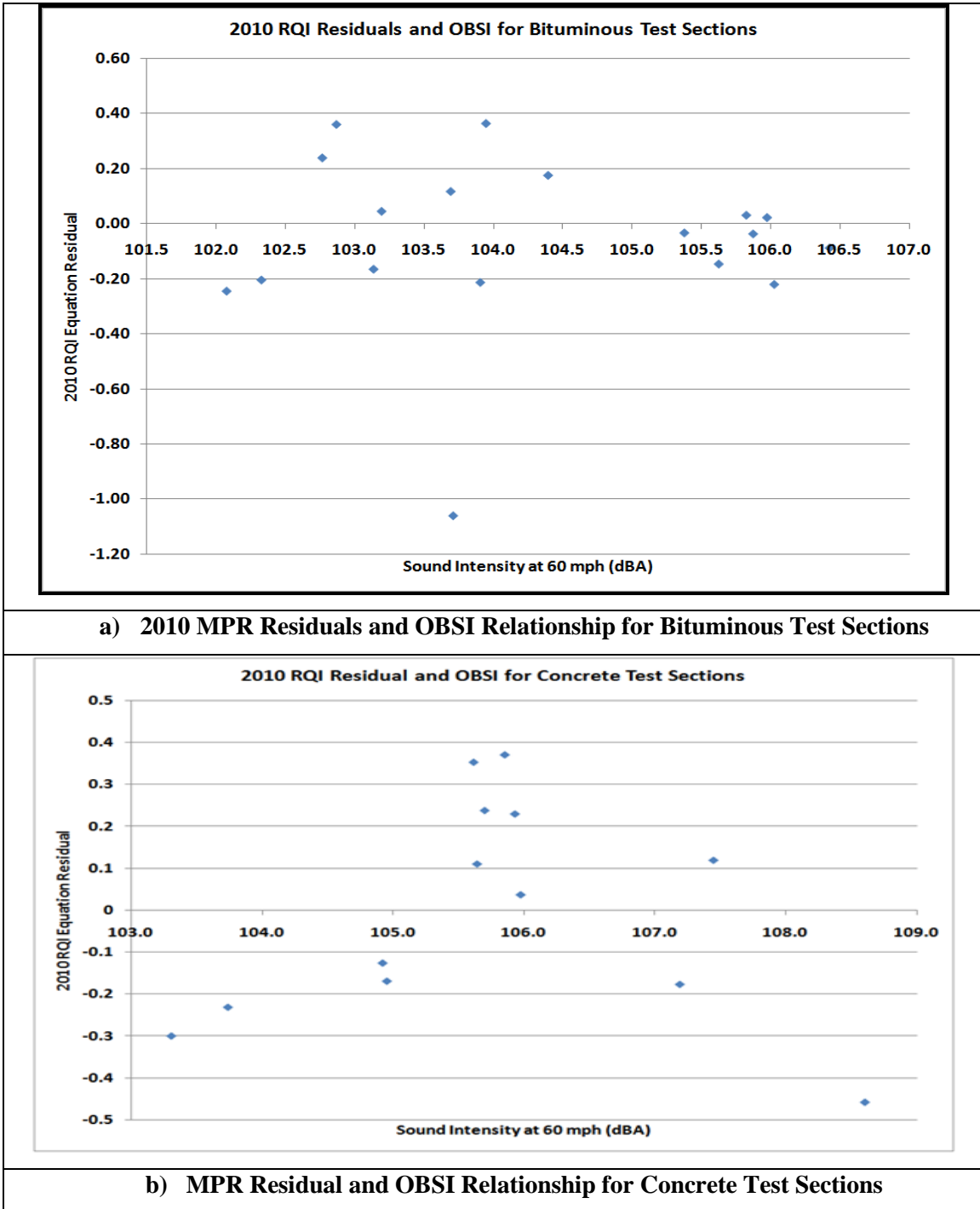
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### 18 **Sequence Examination**

19 The ratings of the test sections appear to be influenced by the sequence that the sections were  
20 tested. It is logical to expect that volunteers retain information by the previous section when  
21 rating the next section. This is evident by test section 6 (Lake Road). The previous section was  
22 on I-494 (concrete) and then this section was on bituminous at a reduced speed. Test section 6  
23 was almost 8 decibels lower than test section 5 when tested at the speed limit. Eight decibels  
24 will be a noticeable drop in noise and that is the most likely reason to why the test section had a  
25 1.1 increase in the MPR value from the 1997 calculated MPR.

26 Sequence is also noticeable on the concrete test sections taken from I-94 (sections 20-27). The  
27 first test section in this series had an average MPR value of 3.6 which was 0.5 less than the  
28 calculated MPR value. The subsequent test sections had a decreasing calculated MPR value and  
29 thus the MPR value from the ride survey followed this trend, but because the first test section in  
30 this series had a lower MPR, that trend continued throughout the test sections. Figure 10 plots the

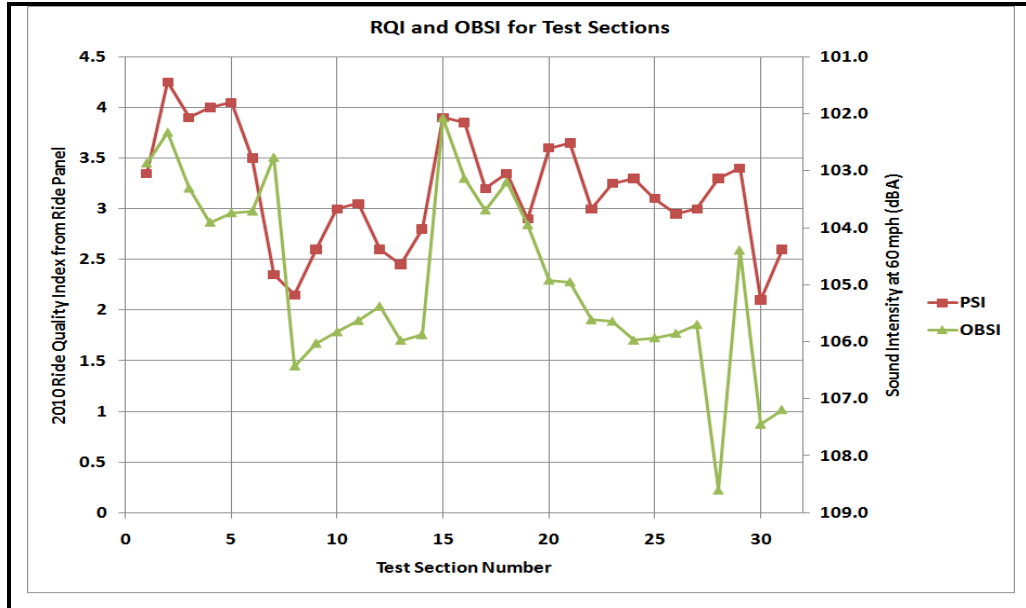
- 1 RQI residual against OBSI. This may indicate that tire pavement interaction noise does not
- 2 explain anomalies in the pavement rating.



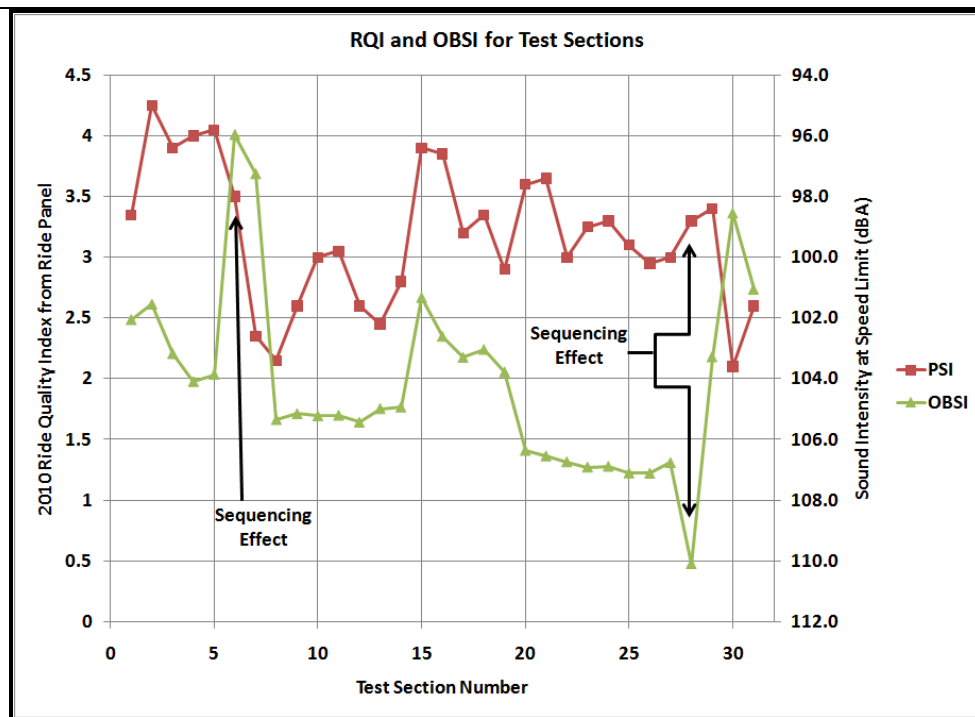
**FIGURE 9 – 2010 MPR Residuals Versus OBSI**

- 3
- 4
- 5





a) PSI and OBSI (60 mph) Correlation



b) MPR and OBSI (Speed Limit) Correlation

FIGURE 10: PSI and OBSI Correlation

1  
2

3 **Re-Examination of Data using Ride Number Instead of IRI**

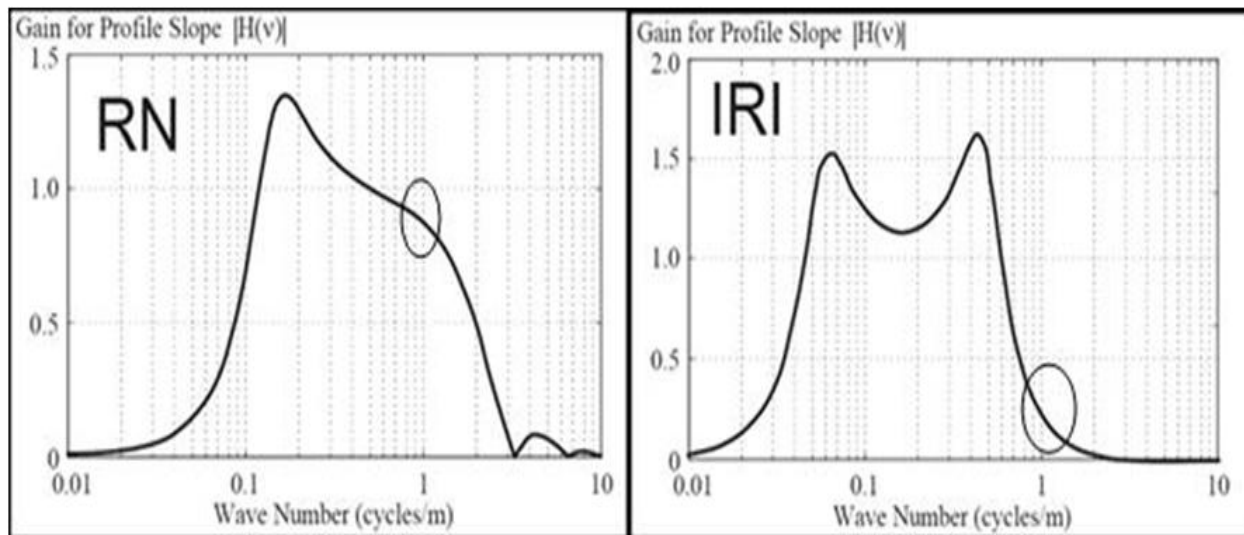
4 It is noted that IRI may not be as sensitive to certain dominant surface wavelengths as Ride  
5 Number (RN). The latter is characterized by a gain algorithm that accommodates a better range

1 of common surface waveforms. It was hypothesized that RN may therefore be a better variable  
 2 than IRI in evaluating the effect of certain surface features. Similar analysis, of curve fitting,  
 3 examination of outliers and sequence were performed with RN instead of IRI.

4

5 The plot on the right (FIGURE 11) shows the sensitivity of the IRI to various wavelengths. The  
 6 three-foot length of most dips corresponds to one wave cycle per meter. The gain factor in the  
 7 IRI plot for this wave number is about 0.2 so it has limited impact on the IRI used to calculate  
 8 the RQI. Ride Number (RN) estimates the roughness a car passenger perceives as a function of  
 9 wave numbers. Here, the same wave number has a gain factor of about 0.8. Therefore, the RN  
 10 is much more sensitive to the dip than the IRI or derived RQI is.

11



12

13 Figure 11: Comparison of Gain Algorithms of IRI to RN (4).

14

15

16 However, in the sections tested and with the data obtained, the anomalies in rating when  
 17 compared to RN, anomalies were not explained by OBSI and there was evidence of sequencing  
 18 effect similar to what was observed with IRI

19

20

21

## 1 CONCLUDING REMARKS

2 This study examined MPR IRI AND OBSI of 31 contiguous sections to ascertain the possibility  
3 of pavement noise influencing anomalous rating. Based on the analysis conducted, but there is no  
4 tenable statistically significant evidence that OBSI explains anomalies in MPR.

5

6 Instead there was evidence of correlation of OBSI to IRI and MPR implying that rougher  
7 pavements tend to be noisier.

8

9 Sequencing of the test sections probably biased some of the ratings. The succession of  
10 Concrete section (test section 5) by a bumpy bituminous surface (test section 6) may have biased  
11 the rating of the latter. This anomaly was observed in the transition from Manning Avenue to  
12 interstate 94 in a reverse form. It may however require further testing to and a larger data set to  
13 unquestionably attribute anomalous ratings to sequencing in general but this study may have  
14 been influenced by that psycho acoustic phenomenon. This is the first pavement rating that was  
15 followed immediately by a noise evaluation. The effect of age of pavements and the noise  
16 spectral changes are not known. Subsequent pavement rating should include corresponding  
17 noise evaluation in order to increase the sample space and fully examine the sequencing  
18 phenomenon.

19

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## 25 **ACKNOWLEDGEMENTS**

26 Mn/DOT’s Karla Raines and Office Director Keith Shannon facilitated the provision of  
27 volunteers for the survey. Curt Turgeon and Maureen Jensen provided the initiative to measure  
28 pavement noise behind the rating crew. David Janisch provided ride data. Steve Olson and John  
29 Pantelis measured sound intensity levels in the thirty one test sections.

30

31

1 **DISCLAIMER**

2 This research paper presents results of the research conducted by authors and do not necessarily  
3 reflect the opinions or constitute a standard for Mn/DOT or other entity.

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