ESTABLISHING IRI THRESHOLDS FOR THE DISTRICT OF COLUMBIA

DRAFT FINAL RESEARCH REPORT

March 30, 2009

Submitted to:

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Technical Report Documentation Page

1. Report No. **DDOT-IPMA-IRI-001**			2. Report Date 03/26/2009	
3. Title and Subtitle Establishing IRI Thresholds for the District of Columbia			4. Contract or Grant No. PO 222711	
5. Author(s) Dr. Stephen Arhin, P.E. Dr. Errol C. Noel, P.E.				
6. Performing Organization Name and Address Howard University Transportation Research Center 2366 Sixth Street NW, Suite 130 Washington, DC 20059			7. Type of Report and Period Covered.	
8. Sponsoring Agency Name and Address District Department of Transportation Infrastructure Project Management Administration 64 New York Avenue, NW Washington, DC 20009				
9. Supplementary Notes				
10. Abstract The Federal Highway Administration (FHWA) requires each state to report the International Roughness Indices (IRI) of its road network in the annual Highway Performance Monitoring System (HPMS). The reported IRI for road segments are compared to the national standards developed by the FHWA based on national data. Deviations from the national standards are used to identify road segments that need to be included in repair or maintenance programs. The FHWA established, for all road classes, an IRI of 170 in/mi or less is deemed "acceptable", and 95 in/mi or less is categorized as "good". The use of the IRI for identifying sections of highways for repair and rehabilitation has been under review in several states. There is concern that the national values of the IRI are often in conflict with the ride smoothness perceived by an average citizen in the specific jurisdiction. This study obtained the ride ratings of residents of the District of Columbia and correlated them with the IRI values for selected road segments. This report presents the IRI thresholds developed for the District of Columbia based on the regression models obtained and the standard IRI thresholds for newly constructed pavement.				
11. Key Words Pavement smoothness IRI Pavement condition index		12. Distribution Statement		
13. Security Classif.(of this report) Unclassified	14. Security Classif.(of this page) Unclassified		15. No. of Pages 33	16. Price

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1.0 EXECUTIVE SUMMARY

The District Department of Transportation (DDOT) is committed to improving the ride quality of its roadway network through continued research and the application of innovative methods for the maintenance and rehabilitation of its roads. The Federal Highway Administration (FHWA) requires each state to report the International Roughness Indices (IRI) of its road network in the annual Highway Performance Monitoring System (HPMS). The reported IRI for road segments are compared to the national standards set by the FHWA. Deviations from the national standards are used to identify road segments that need to be included in repair or maintenance programs. The FHWA established, for all road classes, an IRI of 170 in/mi or less is deemed “acceptable”, and 95 in/mi or less is categorized as “good”. The use of the IRI for identifying sections of highways for repair and rehabilitation has been under review in several states. There is concern that the pure values of the IRI are often in conflict with the ride perceived by an average citizen in a community. Most states have since established IRI thresholds based on the ride quality perceptions of the resident motorists. The problem appears to be more acute in urban areas where the dominant features are arterials and local streets and where the public’s tolerance for pavement roughness is relatively higher because of low operating speeds. In this research, the Howard University Transportation Research Center (HUTRC) conducted a study to explore the potential of establishing IRI thresholds for the District’s pavements based on the opinion of citizens who rode in vehicles that traveled on selected road segments where IRI values were previously obtained using the FHWA-approved methodology (by automation). The average IRI value of each segment was derived from observations during one-direction of travel. The results of the correlation analyses conducted on the data yielded statistically significant results at 5% level of significance which enabled the establishment of the District's IRI thresholds that are more in line with motorists' perception. DDOT has also established a mechanism for paying contractors based on expected IRI values for new pavement. The IRI value for "good pavement" is typically used for full payment, while that of "acceptable pavement with defect correction" qualifies for partial payment, with the remainder disbursed after correcting defects on the new pavement. The average of the limits of the IRI values from the regression models and the payment limits were used in determining the recommended IRI thresholds for the District of Columbia presented in the table below:

IRI Thresholds Developed for Three Roadway Classifications in the District

RIDE QUALITY	FREEWAYS	ARTERIALS	COLLECTORS
Good	< 124	< 182	< 188
Acceptable	125-218	183-281	189-318

The recommended IRI threshold would improve DDOT's ability to select projects in need of maintenance, repair and reconstruction that are supported by both instrumented data and public opinion. If implemented, the IRI threshold developed in this research would reduce the type, scope, and cost of the projects that would otherwise be selected by use of the recommended FHWA IRI thresholds.

2.0 PROBLEM STATEMENT

Since the development of the International Roughness Index (IRI) in the early 90's, all states have been required by the Federal Highway administration (FHWA) to report IRI results through their annual Highway Performance Monitoring System (HPMS). International Roughness Index is a standardized measure of the response of a standard vehicle to roadway profile and roadway roughness. As the name implies, its purpose is to provide an indication of the roughness/smoothness of a road and forms a common basis for comparing ride quality on roadway sections. The index is typically expressed in "inches per mile". Higher IRI values generally represent rougher roads, while lower IRI values mean smoother roads. Over the past several years substantial progress has been made in improving ride quality through pavement management programs thereby reducing IRI values.

With the emphasis on improving pavement smoothness nationally, FHWA has set a performance goal of improving the IRI values of the National Highway System by 2008. The District Department of Transportation (DDOT) is striving to improve ride quality in the District by lowering IRI values as well. This has been one of the many long-standing commitments to maintaining a high quality of road conditions in the District. Currently, DDOT uses the IRI standards set by FHWA. These standards may not correspond to the District's roads and driving conditions since most of the data used in establishing the IRI standards were collected under varying set of scenarios and conditions that are more likely compatible in other states. These include rural, high speeds and wide roadways which may skew the standard ranges of IRI where ride quality shifts from unsatisfactory to satisfactory from the motorist's point of view. Drivers' perception of the severity of pavement conditions also varies from jurisdictions to jurisdiction, which plays an important role in determining an acceptable ride quality. Due to these variations in motorists' perception of ride quality, the IRI standards may not reflect the true ride quality expectations of the District's residents. This research is geared toward establishing citizens' levels of satisfaction with the ride quality of the District's roads and to determine the new IRI thresholds that more closely corresponds to the ride perception of the District's residents. The revised IRI thresholds have the potential for reducing the number of road segments that may fail the basic FHWA IRI standards, while being perceived as satisfactory by the District's citizens.

3.0 RESEARCH OBJECTIVES

This research is aimed at using citizens' perception to establish the IRI standards for the Districts' roads. In particular, the following objectives will form the basis of this research:

- Development of a relationship between the subjective ride quality rating (PSR) provided by citizen subjects and the objective ride quality data (IRI) for various roadway classifications.
- Develop IRI thresholds which are compatible with the PSR acceptable by the average DC resident for different the road classifications.

4.0 LITERATURE REVIEW

Pavement smoothness or roughness can be expressed as the extent of the non-existence or existence of surface irregularities that affect the ride quality of road users. Research has shown that smooth roads, on the whole, costs highway agencies less over the life of the pavement resulting in decreased highway user operating costs, delay costs, fuel consumption and maintenance costs. Pavement roughness is measured by various automatic multifunctional measuring instruments or devices and is quantified using the International Roughness Index (IRI), an internationally accepted parameter. IRI was first defined in the late 70's by NCHRP Report 228 and was adopted by the World Bank *[1]* as a universal scale. The IRI is currently required among the data on the annual Highway Performance Monitoring System (HPMS) submitted to the FHWA by each state.

IRI is typically measured by automation using a road profiler, which produces a series of numbers to represent the profile of the road by combining a reference elevation, height relative to the reference, and longitudinal distance. Examples of road profilers include the Profilograph, Dipstick Auto-Read Road, and Inertial Profilers *[2]*. Response-type road roughness meters or profilers are typically used to collect IRI data and are usually mounted in specialized vehicles with computer technology to monitor pavement roughness. The device records the displacement of the vehicle chassis relative to the rear axle per unit distance traveled, usually in terms of counts per mile or foot *[3]*. Other instruments measure pavement roughness in terms of the number of inches per mile that a laser, mounted in a vehicle, jumps as it is driven across highways at speeds of over 30 mph. These instruments are connected to calibrated computer models which are used to calculate and report a corresponding number indicating the roughness or smoothness of the roadway driven. This therefore ensures that the IRI values reported are comparable and repeatable irrespective of the test vehicle *[3]*.

Road smoothness may also be quantified in the form of the Present Serviceability Rating (PSR), which depends on subjective human evaluation of ride quality. The PSR was developed in 1962 by the AASHO Road Test. The rating ranges from zero (impassable) to 5 (perfect). It has been established through studies conducted by FHWA that the smoothness index of highway systems obtained through automation (IRI) can be correlated to the subjective ride experience or evaluation of road users (PSR rating).

Pavement surface roughness is a major concern associated with driving quality. The presence of pavement roughness may cause stress increases in the pavement structure which may result in pavement fatigue which, in turn, could accelerate the pavement's deterioration. Furthermore, a review of pavement roughness indices (together with other pavement measurements), may indicate pavement surface deformation. Pavement deformation could undermine pavement drainage thereby compromising highway safety. Pavement distress also results in a deterioration of the pavement roughness index value. This therefore suggests that the extent of pavement distress could be correlated to pavement roughness indices, including the IRI.

The FHWA recommended a threshold of 170 in/mi (2.7 m/km) for acceptable ride quality in its 1998 strategic plan for the National Highway System. The lower the IRI number the smoother the ride and vice versa. Table 1 provides the pavement condition criteria for all functional road classifications in the national highway system, together with the estimated PSR rating *[4]*.

Table 1: FHWA Pavement Condition Criteria [4]

Road Quality Terms	IRI Threshold (in/mi)	PSR Rating
Good	< 95	> 3.5
Acceptable	< 170	> 2.5

Most jurisdictions in the United States rely on pavement indices to determine which road segments in their road network need maintenance or improvement. These indices include the IRI and the Pavement Condition Index. Since 1990, the Federal Highway Administration (FHWA) has required states to report road roughness on the IRI scale. This mandatory report has caused most states to take a second look at the national IRI standards, which may or may not truly reflect actual pavement roughness or smoothness perceived by motorists in local jurisdictions. In particular, the application of the national IRI standards has been challenging to urban jurisdictions due to heavy traffic volumes, expected traffic interruptions and considerably lower travel speeds.

In 2003, the Pennsylvania Department of Transportation (PENNDOT) conducted a study that resulted in the development its threshold values on the IRI scale which represents the ride quality perceived by the traveling public in that State *[5]*. PENNDOT conducted field evaluations in 6 counties on 4 different functional roadway classifications (300 segments in all) with reported IRI values ranging from 70 to 250 in/mi. In 5 of the 6 counties, total of 80 subjects each were trained and participated in the study, while in the sixth county, 100 subjects participated. The subjects evaluated the roadways using the Weaver/AASHO scale (ranging from 0 to 5, where 5 as excellent and 0 as impassable) on their perception of the ride quality while riding in minivans. In addition, the subjects rated their level of satisfaction with the ride quality by responding to a set of questions related to the road attributes (e.g., lane widths, shoulders, sight distance, etc.). A simple regression analysis was conducted for IRI values and the reported percentage of subjects satisfied with the ride quality. From the results, about 62.6%, 67.9%, 72% and 61.5% of the subjects were respectively satisfied with the ride quality for Interstate Highways, National Highway Systems roads, Secondary roads with over 2,000 AADTs and Secondary roads with less than 2,000 AADTs. IRI threshold values were also established for varying percentages of road-users' satisfaction of ride quality.

In the fall of 2000, the Washington State Department of Transportation (WSDOT) in conjunction with the Washington State Transportation Center (TRAC) at the University of

Washington performed a similar study in which the IRI data set previously obtained on some segments were correlated to that of the motorists' perception of Washington State's road quality *[6]*. The data collection was conducted in two parts. Over 2,500 mailout-mailback survey forms were first sent to registered vehicle owners in the Seattle and surrounding area who were randomly chosen after their vehicle license plate numbers were pictured as they entered and exited the SR 520. Fifty six of those who responded to the mail survey were asked to participate in an actual in-vehicle road survey where they were asked to drive and rate the roughness of 40 predetermined highway segments (PCC or AC pavements). Four types of vehicles used in the study, given that vehicle type could have an impact on the perception of road roughness: a midsize sedan, sport utility vehicle (SUV), pickup truck and a minivan were used. Pavements with low IRI values generally corresponded with low roughness rankings and high levels of user acceptability. The study also established an acceptable ride quality with IRI value of 220 in/mi or less.

The Minnesota Department of Transportation (MnDOT) developed a mathematical model for converting the IRI to the PSR for bituminous and concrete pavements *[7]*. In the process of developing this model in 1997, MnDOT asked 32 citizens to rate the smoothness of more than 120 pre-selected test sections on the state's highway system. The range of the ratings was from zero (very poor) to 5 (very good), with grades in-between for good, fair and poor. Using simple regression analysis, the following regression equations were developed for bituminous and concrete pavements respectively:

$$PSR = 5.697 - (2.104.\sqrt{IRI}) \text{ , and } PSR = 6.634 - (2.813.\sqrt{IRI}),$$

where IRI = International Roughness Index, in m/km.

These regression models enabled MnDOT to set its own IRI thresholds for acceptable pavement conditions.

The City of New York, along with the New York State Department of Transportation (NYSDOT), began an assessment of the quality of the pavements in various jurisdictions using 151 motorists in different community districts *[8]*. This study was conducted in 1995 and enlisted the services of an independent research firm which asked members of focus groups to rate a list of pre-selected roadways on a scale from 1 (good) to 4 (terrible) as they were driven through each segment. However, instead of using the traditional IRI values, NYSDOT engaged services of the Galaxy Scientific Corporation which measured the smoothness of the same segments in terms of "City Roughness Index" (CRI). The reported indices were obtained using the same procedures for obtaining IRI values, except that the CRI is a number that is dependent on the number of "jolts" encountered per mile on short distance segments with high speeds of travel. The tests were applied only to city streets. A regression analysis was conducted for the data obtained from the motorists' perception and the CRI. The percentages of motorists who rated the smoothness of roadways as "good", "fair", "poor" and "terrible" were also reported for each jurisdiction. The results of the study were used to establish the CRI thresholds for city streets in the State of New York.

Concerned about its inability to make pavement repair and maintenance decisions that are supported by motorists' perception, DDOT launched an exploratory study in March 2007 *[9]*. Three classifications of highways were considered in the study: freeways, arterials and collectors. The study utilized IRI averages for both directions of travel on the selected segments of roadways. The perception of subjects who traveled in one direction was also observed. The correlation between IRI and motorist perception for freeways and local streets, based on the R^2

statistic, were 0.56 and 0.63 respectively. The R^2 value for collectors was determined to be 0.24, considered to be relatively low. Although the exploratory study showed some promise from a statistical perspective, the report recommended an expanded study, with more segments where direction of travel would be considered for the specific lanes selected for each road segment.

Several other states have also conducted studies to gauge motorists' satisfaction with the smoothness of roadways, and to establish ride quality benchmarks *[10]*. Presented in Table 2 is a summary of "acceptable" IRI threshold values for all pavements established as of 2004, based on the results of studies conducted in the following selected states:

Table 2: IRI Threshold Values for "Acceptable" Ride Quality as of 1998[10]

STATE	THRESHOLD IRI (in/mi)
Kansas	< 164
Washington	< 220
Indiana	< 230
Louisiana	< 300
Connecticut	< 127
Minnesota	< 115

In 2008, DDOT established standards for IRI for new pavement to be used in identifying the payment mechanism for pavement contractors *[11]*. The standards for accepting new pavements are based on IRI surveys of 25-ft segments of roads. The threshold averages for good pavement are equivalent to IRI_c, defined as the maximum IRI for full pay. These values are presented for freeways, arterials and collectors, and local roads. Similarly, IRI_f is equivalent to the threshold for defect correction on new pavements. From the definitions, IRI_c could be classified as "good" while IRI_f could be classified as "acceptable". The thresholds are presented in Table 3.

Table 3: DDOT's IRI Thresholds for New Pavement [11]

New Pavement IRI Limits	ROAD TYPES		
	Freeways	**Arterials/Collectors**	**Local Roads**
IRI_c (Good)	≤80	≤160	≤180
IRI_f (Acceptable)	81-160	161-300	181-350

5.0 RESEARCH METHODOLOGY

In establishing IRI benchmarks for the District of Columbia, the research team conducted a survey using DC residents who gave their opinions on the smoothness of selected road segments, based on the Weaver/AASHO Scale. The ratings were obtained while the subjects were driven over selected road segments in the City. Using simple regression analysis methods, the average ratings of the drivers' perception of the smoothness for each segment were correlated with the corresponding segments' IRI values obtained from recent DDOT pavement smoothness surveys. Based on the resulting regression model, benchmark IRI values for each roadway classification were obtained. A 5% level of significance was used for the analyses. The average of the thresholds obtained from the regression models and the established values for IRI_c and IRI_f (for each road classification) were then calculated and presented as IRI thresholds for the District of Columbia.

5.1 Selection of Segments

DDOT provided the research team with IRI data on all road segments collected in 2007 through 2008. The research team selected segments that represented the various functional roadway classifications of the District. For each segment, the specific lane, direction of travel, and corresponding IRI observations were obtained from DDOT. In all, 122 segments were selected and were grouped into the following 3 classes: interstate/freeways (30), arterials (62) and collectors (30). The segments selected had IRI values raging from 97 to 499 in/mi.

5.2 Subject Selection and Training

Subjects for the survey were recruited by DDOT through advertisements in all the 8 Wards in the District of Columbia. Over 110 potential subjects responded to the advertisement out of which 66 actually participated in the survey. The ages of the subjects ranged between 21 and 61. The survey was conducted on June 7, 2008. Three groups were formed (22 subjects each) for the survey of each of the three roadway classes. Prior to the commencement of the survey, instructions on how to provide ratings using the AASHO/Weaver form, were given to all the subjects. The survey lasted between 3-4 hours (with breaks) after which each subject was given a small financial token for participating. Each group of subjects was driven over the selected lane of each segment and each member recorded his/her individual perception of the ride using the survey for provided.

5.3 Survey Instrument

Figure 1 shows the Weaver/AASHO form used by the subjects for rating the smoothness of the segments. The scale ranges from 0 (“impassable”) to 5 (“perfect”). As shown in the figure, the scale has intermediate ratings which are labeled as “very good,” “good,” “fair,” “poor” and “very poor”. For each segment driven, the subjects were asked to indicate on the scale the position that corresponded with their best description of their feeling about the segment smoothness. A survey form was provided for each segment and for each subject. The subjects familiarized themselves with the survey form prior to being driven over the selected segments.

5.4 Survey Vehicles Used

The survey was conducted using five 2004 Ford E-350 XL (Super Duty) Minivans, hired from the International Limousine Services, Inc. The fleet company provided drivers who were familiar with the City’s road network. Prior to the actual survey, the research team and the fleet company drove over the pre-selected lanes of each segment to determine the best route and to estimate the length of time needed for the survey.

5.5 IRI Values

The IRI values were previously collected between 2007 and 2008 by a contractor retained by DDOT. The data was provided to HUTRC in a spreadsheet format (EXCEL). The segments used, together with their corresponding IRI values, were extracted from this data. Due to the length of time between the collection of the segment’s IRI values and the actual ride quality rating survey, the research team confirmed that none of the selected segments had been

Gender: ___ MALE ___ FEMALE
Age Group: ___18-35 ___ 36-55 ___ Over 56

Please evaluate the ride quality of this road segment on the following scale by placing a mark across the part of the vertical line that best describes the feel of the ride.

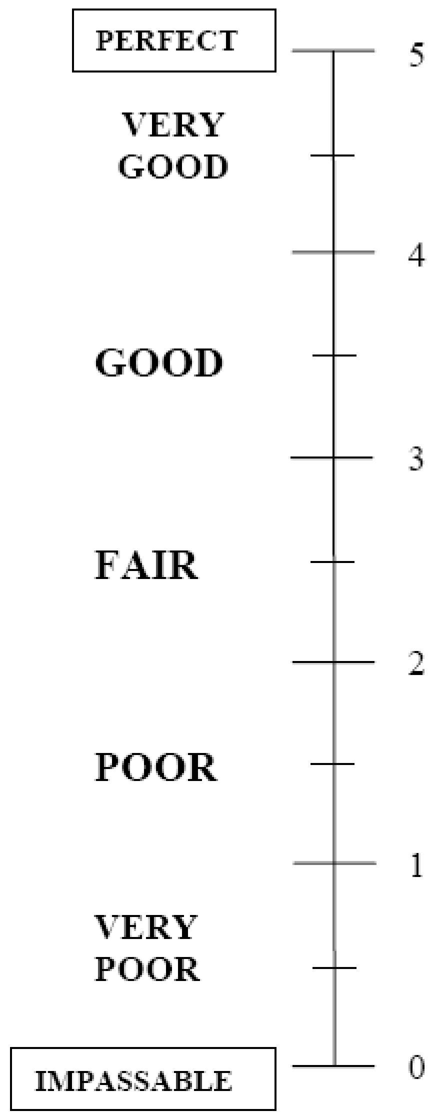

Figure 1: The Weaver/AASHO scale of ride quality

re-surfaced, re-constructed, or utility work had been done in that period. Segments which had undergone some structural changes were excluded from the survey. The segments chosen represented 3 functional roadway classifications in the District of Columbia: Interstate/Freeways, Arterials and Collectors. The IRI values used in this study represent the average of IRI values reported for the inbound and outbound of each segment in a particular lane.

5.6 Data Extraction

The survey forms were collected from the participants at the end of the survey. The rating for each segment by each subject was recorded in an EXCEL spreadsheet. The corresponding IRI values obtained from DDOT previously was also recorded. The combined data resulted in a matrix of ratings for each segment exemplified in the table below:

Segment	IRI	Ride Quality Rating by each subject							
		1	*2*	*3*	*4*	…	…	…	*22*
1	Y_1	x_{11}	x_{12}	x_{13}	x_{14}				
2	Y_2								
3	Y_3								
4	Y_4								

5.7 Statistical Analysis

For each segment, the average of the subjects' rating was computed. The average ratings for the segments were correlated to the IRI values using regression analysis methods. This was conducted using Microsoft EXCEL and SPSS. After a series of data transformations, the following generalized regression model was deemed to be adequate:

$$\ln(IRI) = \ln \alpha + \beta\,(PSR) + \varepsilon,$$

where IRI is the dependent variable and PSR is the independent variable. The constants α and β are the coefficients of the regression model with an associated error of ε [$\varepsilon \sim N(0, \sigma^2)$]. The statistical significance of the regression coefficients were tested at 5% level of significance. Similarly, the overall statistical significance of each regression model for each classification of roadway segment was tested using the F-test at 5% level of significance. The F-test, tests the significance of the overall model by determining if the variance accounted by the model is reasonably large. If the associated *p*-value of the F-test is less than 5% (0.05), then the regression model is acceptable and that the hypothesis of the non-existence of a relationship between the independent variable and the dependent variable is rejected. In addition, the regression model was checked for homoscedasticity (constant variance) using residual plots while checking for normality using the normal probability plots. The residual plots should show the errors randomly distributed about the mean line (zero) or is rectangular, with a concentration of points along the center. In a normal probability plot, if all the data points fall near the line, an assumption of normality is reasonable. Otherwise, the points will curve away from the line, and an assumption of normality is not justified.

For each regression model, the coefficient of determination or the R^2 value is also reported. This is the amount of variability in the data explained or accounted for by the regression model. It is worth noting that the R^2 value of a regression model will increase with the introduction of a new variable, although the new model may not be necessarily better or superior. Furthermore, if the dependent and independent variables are related in a non-linear fashion, the R^2 value will often be large, although linearity is assumed.

6.0 RESULTS

The results are based on the analyses of the relationships between the IRI values obtained and the District's motorists' perception of road smoothness on all road segments and by the grouped classifications. A total of 132 road segments were surveyed. The results are presented in two sections: descriptive statistics and regression analysis.

6.1 Descriptive Statistics

The following table (Table 4) presents a summary of descriptive statistics of interest for the various types of roadways. The analysis was conducted using Microsoft EXCEL.

Table 4: Descriptive Statistics for IRI Values

Classification	Mean IRI (in/mi)	Mean PSR Rating	IRI Standard Deviation(in/mi)	PSR Standard Deviation
Freeways/Interstates	207.88	3.40	101.24	0.23
Arterials	225.52	3.20	55.32	0.45
Collectors	285.45	2.58	72.43	0.23

A PSR rating between 2 and 3 on the AASHO/Weaver scale may be considered as fair while a rating above 3 indicates a good ride quality. Thus, on the average, motorists' in the District considered road segments with a high IRI value of about 285 in/mi as fair. Interstates and freeways had the lowest mean IRI value (207.88 in/mi) with a corresponding high PSR rating (3.40) which represents a good ride quality. Collectors had the highest mean IRI value (approximately 286 in/mi) with a mean PSR rating of 2.58. However, on the Weaver/AASHO scale, a rating of 2.58 corresponds to a fair ride quality. Figure 2 shows a graphical display of the mean IRI values for the classes of roadway segments surveyed.

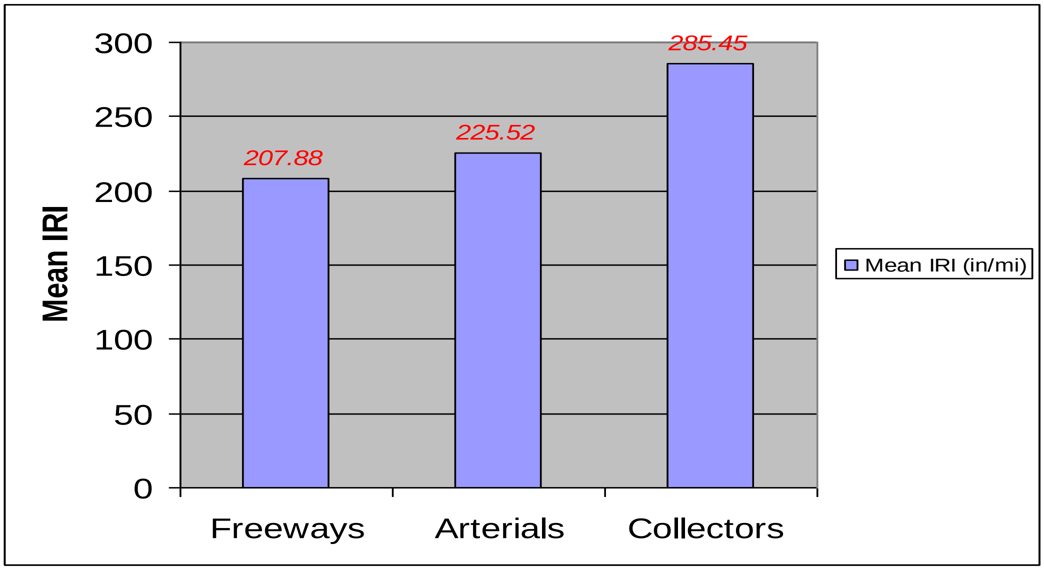

Figure 2: Average IRI Values by Roadway Classification

6.2 Regression Analysis

6.2.1 Freeways/Interstates

Data for the 30 freeway segments surveyed in this project were analyzed and the results showed that the regression model is adequate at 5% level of significance. The summary of the regression analysis indices are presented in Table 5. The scatter plot with fit and residual plot for the model are presented in Figures 3 and 4 respectively.

Table 5: Summary of Regression Analysis for Freeways/Interstates

Test Statistic	Value	P-Value
R^2 Value	0.58	n/a
ANOVA: Regression ***F-Value***	34.07	0.00
Significance of Regression Coefficients (***t- Statistic)***	β_0 : 6.672	0.00
	β_1 : -0.4202	0.00

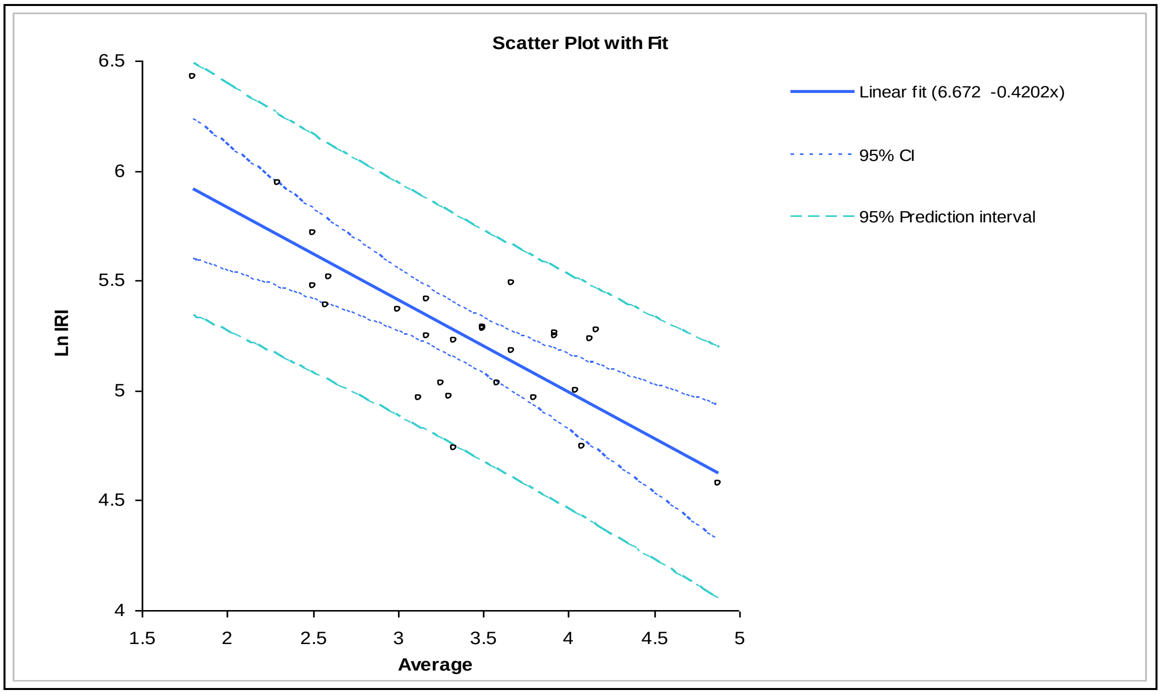

Figure 3: Scatter Plot with Fit for Freeway Regression Model

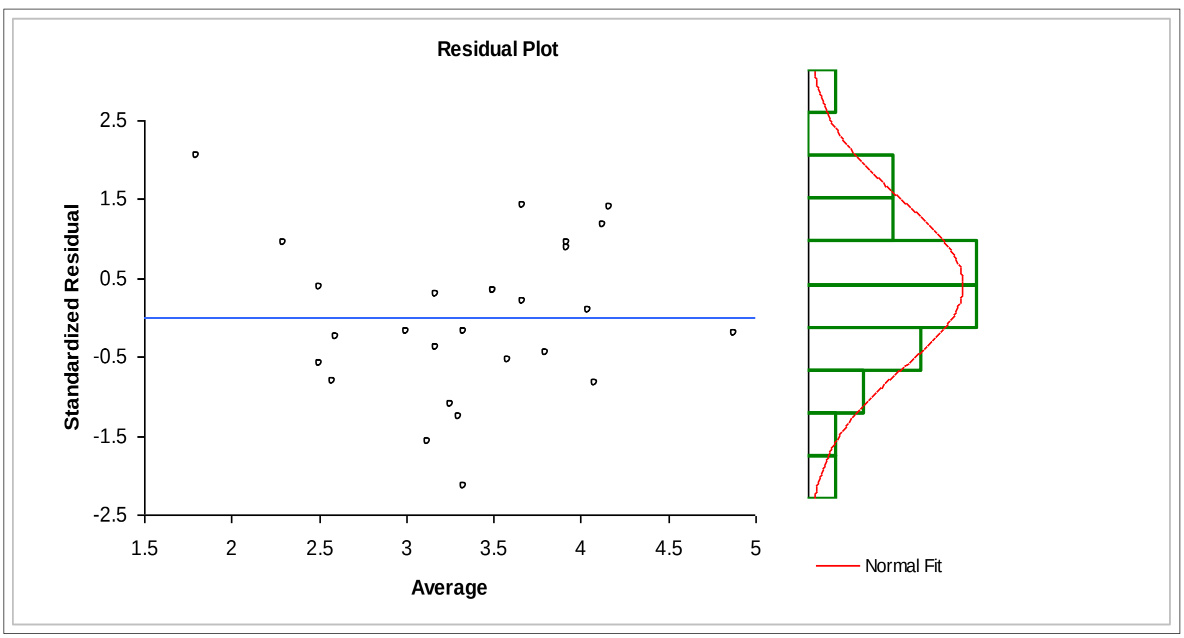

Figure 4: Residual Plot for Freeway Regression Model

Since the p-value for the F-statistic is less that 5%, it indicates that the regression model is adequate based on the data collected. In addition, the t-statistics of the coefficients β_0 and β_1 were found to be statistically significant at 5% level of significance.

The resultant regression equation is:

$$\ln \text{IRI} = 6.672 - 0.4202 \text{ (PSR)} \qquad (1)$$

6.2.2 Arterials

Based on the regression analysis conducted on the 62 arterial segments, the results indicate a statistically significant regression model at 5% level of significance. This is indicated by the summary in Table 6. Presented in Figures 5 and 6 are respectively the scatter plot with fit and residual plot for the regression model.

Table 6: Summary of Regression Analysis for Arterials

Test Statistic	Value	P-Value
R^2 Value	0.48	n/a
ANOVA: Regression ***F-Value***	53.64	0.00
Significance of Regression Coefficients (***t- Statistic)***	β_0 : 6.191	0.00
	β_1 : -0.2483	0.00

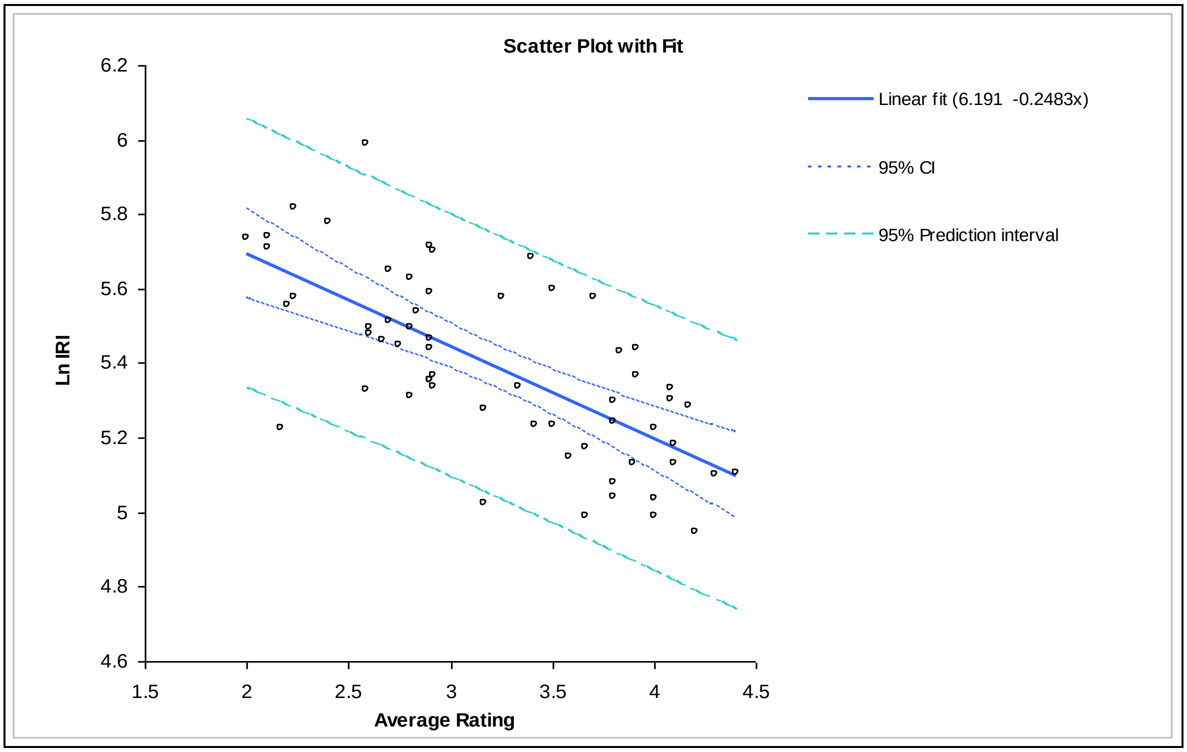

Figure 5: Scatter Plot with Fit for Arterials Regression Model

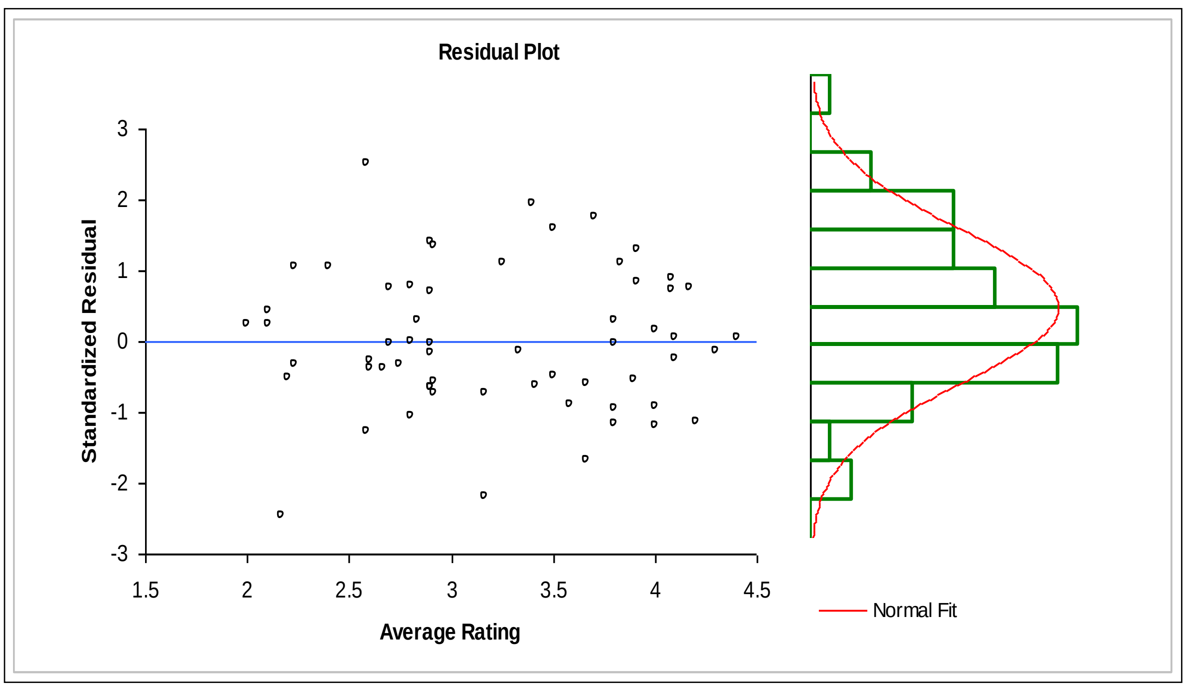

Figure 6: Residual Plot for Arterial Regression Model

The *p*-values for all the major regression indices were found to be less than 5%, thus indicating an adequate regression model. The model explains about 48% of the variations in the data (based on the R^2 value). The resulting regression equation was determined to be:

$$ln\ \text{IRI} = 6.191 - 0.2483\ (\text{PSR}) \qquad (2)$$

6.2.3 Collectors

Similarly, a statistically significant regression model was developed for the correlation between the IRI and the PSR rating for the arterial roads surveyed. The analysis was conducted at 5% level of significance. The primary regression indicators, as in the previous cases, showed a strong correlation between the independent variable and the dependent variable. The summary of the results are presented in Table 7 with scatter plot with fit and residual plot for the regression model presented in Figures 7 and 8 respectively. The analysis resulted in the following regression equation:

$$ln\ \text{IRI} = 6.599 - 0.3772\ (\text{PSR}) \qquad (3)$$

The plots also validate the underlying regression assumptions presented earlier.

Table 7: Summary of Regression Analysis for Collectors

Test Statistic	Value	P-Value
R^2 Value	0.51	n/a
ANOVA: Regression ***F-Value***	29.63	0.00
Significance of Regression Coefficients (***t- Statistic)***	β_0 : 6.599	0.00
	β_1 : -0.3772	0.00

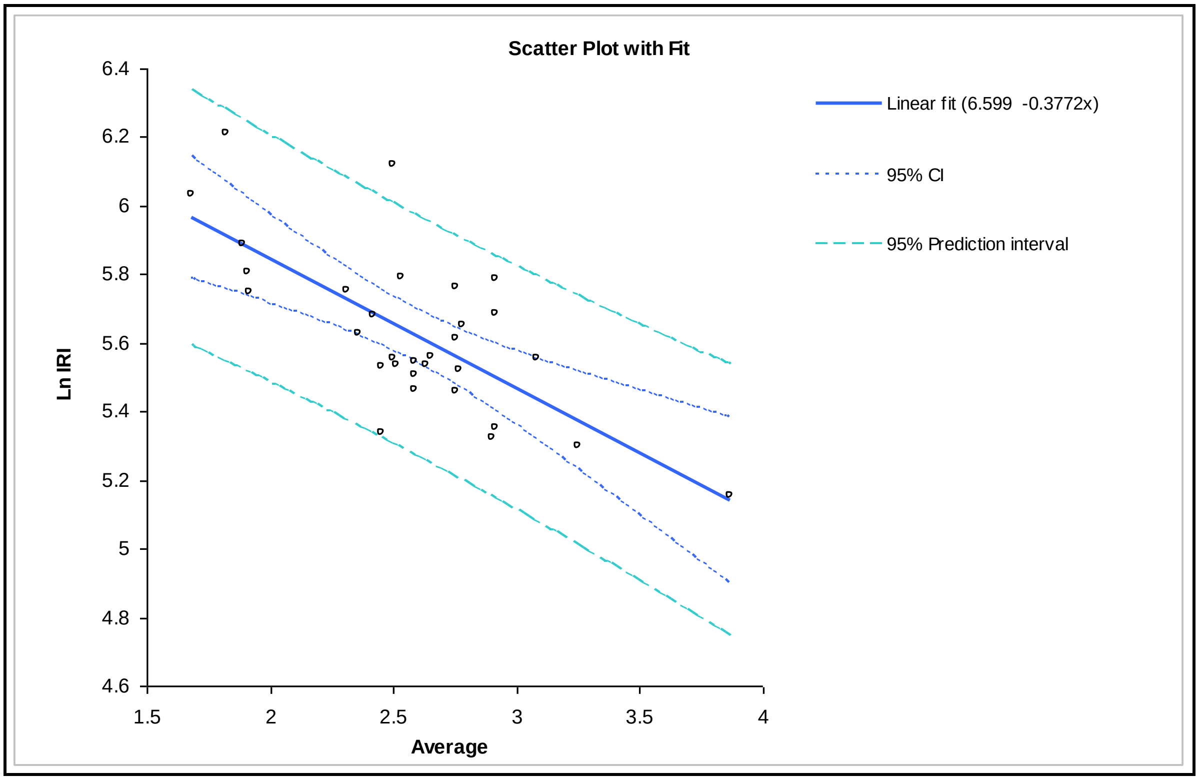

Figure 7: Scatter Plot with Fit for Collector Regression Model

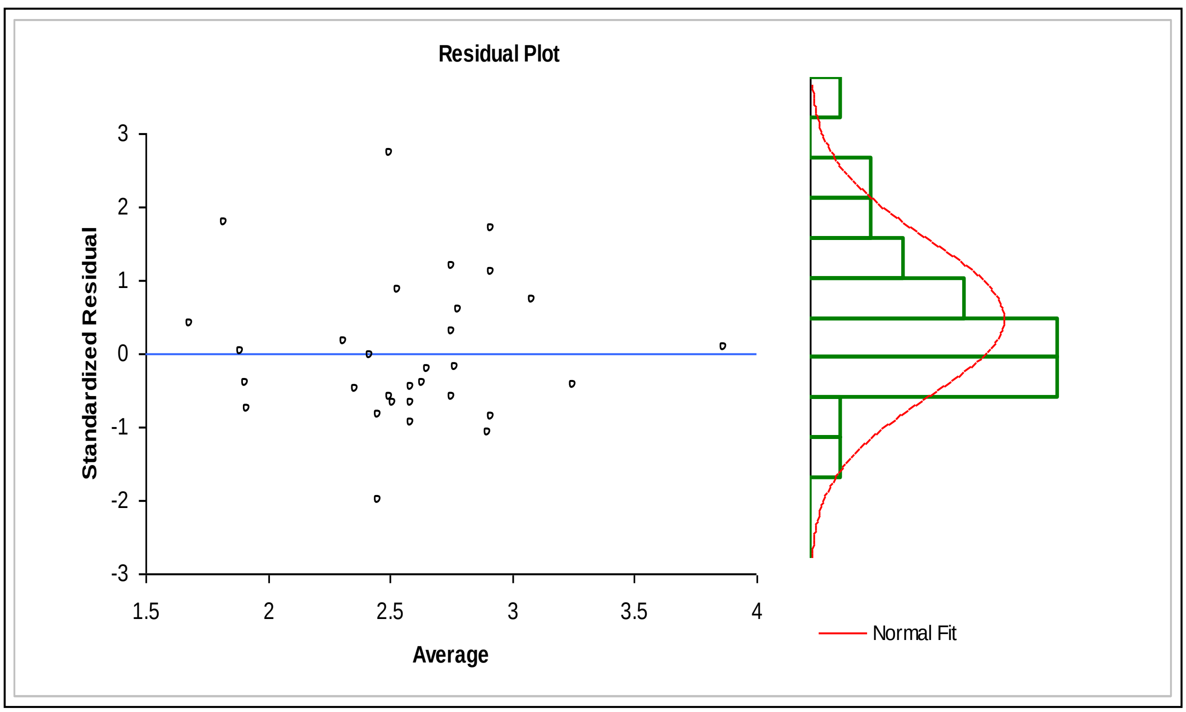

Figure 8: Residual Plot for Collector Regression Model

7.0 IRI THRESHOLDS FOR THE DC

Based on the regression analyses conducted at 5% level of significance, the threshold IRI values (based on motorists' perception of ride quality) can be inferred. The thresholds derived from the analyses are presented in two-fold: based on FHWA pavement condition scale as presented in Table 1 and on the Weaver/AASHO scale range. The regression equations were used in arriving at these thresholds for each type of roadway.

The minimum PSR ratings of 3.5 and 2.5 were used to characterize "good" and "acceptable" IRI thresholds, respectively. These limits were substituted into the regression equations to produce the corresponding IRI limits presented in Table 8.

Table 8: IRI Limits Based on Regression Models

Ride Quality	**IRI Threshold (in/mi) by Roadway Classification**		
	Freeways	***Arterials***	***Collectors***
Good	< 167	< 204	< 196
Acceptable	167- 276	204- 262	196- 286

Using the limits in Table 3 and Table 8, the following threshold values were obtained by computing the average of the limits for each roadway classification. The results, representing the IRI thresholds for the District, are presented in Table 9.

Table 9: IRI Thresholds for DC

Ride Quality	**IRI Threshold (in/mi) by Roadway Classification**		
	Freeways	***Arterials***	***Collectors***
Good	<124	<182	<188
Acceptable	124-218	182-281	188-318

8.0 DISCUSSION

It has been established that some difficulties are experienced when obtaining IRI values for lower functional systems, especially on collectors and arterials. As a result, there are situations where it may not be possible to obtain meaningful roughness measurements with the profiling equipment. Some of the obstacles include speed restrictions, traffic congestion, pavement and intersection treatments, traffic control devices and short section lengths. Also, maintaining constant speed is required in measuring IRI with a profiling equipment. However, some of these obstacles are often overcome by collecting roughness data during non-peak hours or at night, where speed, traffic, and safety are less of a problem. On the other hand, the subjective data was collected under some (or possibly all) of the problematic conditions under which the IRI values may have been collected.

The IRI thresholds recommended by FHWA are 95 and 170 for good and acceptable conditions respectively. These values do not relate to any of the problematic conditions described above. The urban environment was not the focus. In addition, since roadway geometrics vary considerably from state to state, as expected, many states have embarked upon a similar studies to establish threshold smoothness tolerance levels which their driving public is willing to accept, based on prevailing driving conditions.

In this effort the correlation of the two data sets yielded statistically significant regression models within the margin of error, with some moderate R^2 values. The thresholds derived from the IRI limits from the regression analyses and newly-constructed pavement standards, on average, include the perception of motorists in the District of Columbia.

9.0 CONCLUSION

The IRI thresholds derived from the IRI limits from the regression analyses and newly-constructed pavement standards are indicative of a sound statistical assumptions and theory. The samples used in the study reflect the larger population of residents and the road classifications in the District of Columbia. Within the margin of error, the thresholds can be adequately generalized for roadways in the District of Columbia. Since the DDOT is committed to moving in the direction of implementing more appropriate ride quality standards, the IRI thresholds derived in this study could be used to select road segments for inclusion in its pavement maintenance and rehabilitation program. The IRI thresholds are presented in Table 10.

Table 10: IRI Thresholds for Various Roadway Classifications in DC

RIDE QUALITY	Freeways/Interstate	Arterials	Collectors
Good	< 124	< 182	**< 188**
Acceptable	**124-218**	**182- 281**	**188-318**

10.0 RECOMMENDATION

The District of Columbia should consider using the IRI thresholds developed in this research for selecting road segments for inclusion in its maintenance, repair and rehabilitation program. The new thresholds could reduce the number and scope of projects because of the higher IRI thresholds, compared with the recommended standards of FHWA. The new thresholds would produce an economic benefit derived from the fact that fewer segments would qualify for inclusion in DDOT's highway improvement program.

To gauge the extent of the initial favorable economic impact of the thresholds developed in this research, DDOT may consider a comparative study using data for pavement projects planned for the next three years where cost of the projects selected with FHWA IRI standard could be compared with the cost of projects selected with the new IRI threshold.

11.0 REFERENCES

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