Evaluation of Initial IRI Values as Acceptance Criteria for Flexible Pavements

Don Chen
University of North Carolina at Charlotte
dchen9@uncc.edu

Michael Dye
University of North Carolina at Charlotte
mdye2@uncc.edu

Abstract

Smoothness of pavements has been used for construction acceptance and pay adjustment by many state highway agencies. Currently, the international roughness index (IRI) has become the most widely accepted standard to evaluate pavement smoothness. To establish acceptance criteria for a pavement, its initial IRI values (the IRI rating occurs right after the pavement is constructed) needs to be determined and provided to contractors as a quality assurance measure. The determination of initial IRI values for various pavement types is a challenging task. This is mainly due to the variations in pavement data collected across localities and the limited availability of pavement design and simulation tools. This paper presents a method to address this issue. Flexible pavements' terminal IRI values were simulated using AASHTOWare Pavement ME Design, the new AASHTO (American Association of State Highway and Transportation Officials) design software. Then statistical analysis was conducted to derive initial IRI values. Once implemented, this method can be adopted by highway agencies to establish new acceptance criteria for different types of pavements.

Introduction

The ride quality of roadway pavement is extremely important to roadway users [1]. The roughness of the road has been known to reduce satisfaction of the roadway pavement, prove uneconomical to the roadway users, as well as reduce the safety of the travelers [2]. Therefore, setting required smoothness levels, especially the initial smoothness level when the roadway pavement is constructed, increases the chance of improving traveler satisfaction, safety, and economy of the roadway users.

Realizing the importance of the smoothness of pavements, many state agencies have made a large push to adopt quality control/quality assurance (QC/QA) specification programs for pavements in their state. This is done to ensure that roadway pavements are meeting the desired performance and to promote better construction of the roadway pavement. This often results in the reduced variability of the asphalt mixtures and can be linked to longer lasting roadway pavements [3].

The construction QC/QAs are known as end results specifications that specify the standards that the contractor is required to comply or exceed when supplying or producing a product during the construction of the roadway pavements. These specifications explicitly define what materials, proportions, installation methods, and equipment can be used by the contractor during the construction. Once the contractor has built a roadway, it is the state agency's responsibility to accept or reject the roadway as well as attach a price to the completed work adjusted by adherence with required specifications. Generally, the state highway agency will prescribe the specifications and will accept the finished product, while the contractor is responsible for the quality control process [3].

QC/QAs are excellent tools to verify that roadway pavement specifications have been met by the contractor and are becoming a practice worldwide. Several QC/QA measurements exist that help state agencies determine if the specification has been met. The international roughness index (IRI) is the most practiced. IRI was developed as a way for highway agencies to quantify the smoothness of roadway pavements. It is calculated by using mathematical models that accumulate the output of a quarter-car model and dividing the profile length [2]. IRI values are traditionally expressed in inch/mile in the United States and in mm/km in most other countries. They can be used as a measurement for accepting or rejecting the roadway pavements as early as 7 days after being paved [4]. The concept of IRI was developed in 1982 under sponsorship of the World Bank. IRI replaced the profile ride index in 1998 so the same specifications would apply to concrete and asphalt [5]. The Federal Highway Administration (FHWA) later adopted the use of IRI for the highway pavement monitoring system [2]. IRI has become a well-recognized tool and standard of measurement for evaluating pavement ride quality [6], and therefore it is used as the smoothness measurement in this study.

A pavement's IRI can be measured during its service life. However, the initial smoothness (the smoothness right after the pavement is constructed) is the most important QC/QA criterion. It reflects the quality of construction and is an essential condition for the roadway pavements future performance [5]. Several factors can affect a pavement's initial smoothness. Studies have found a wide amount of variations within pavement material properties and within pavement's base/subbase support characteristics. Only a small portion of these variations can be accredited to natural aging and environmental effects. The remaining variance in the pavement material properties occurs during construction [7]. A poor initial smoothness rating can cause the newly constructed roadway pavement to fail QC/QA testing and have a shorter service life [8].

Initial IRI has been used by state agencies to make sure that roadway pavement is meeting design specifications and is meeting the acceptance and payment qualification of roadway construction. Also, contractors have used the initial IRI value as a target to identify and address process control issues quickly and cost effectively [9]. Initial IRI has been used internationally for QC/QA purposes as well. Currently, the Australian State Road Authorities have started this practice [10]. The New England State Highway Agency offers an incentive for contractors that meet their quality standard and a penalty for roadway pavements that do not meet their quality standards [11].

The objective of this study is to determine initial IRI values as acceptance criteria for various pavement classifications. This is a challenging task mainly due to the variations in pavement data collected across localities. To address this challenge, initial and terminal IRI values for flexible pavements was studied through design simulations using the AASHTOWare Pavement ME Design software. AASHTOWare Pavement ME Design is the newer version of the AASHTO (American Association of State Highway and Transportation Officials) pavement design software. The implementation of this concept would allow state agencies to use predetermined initial IRI values as the acceptance criteria for pavements.

Research Methodology

Work Flow

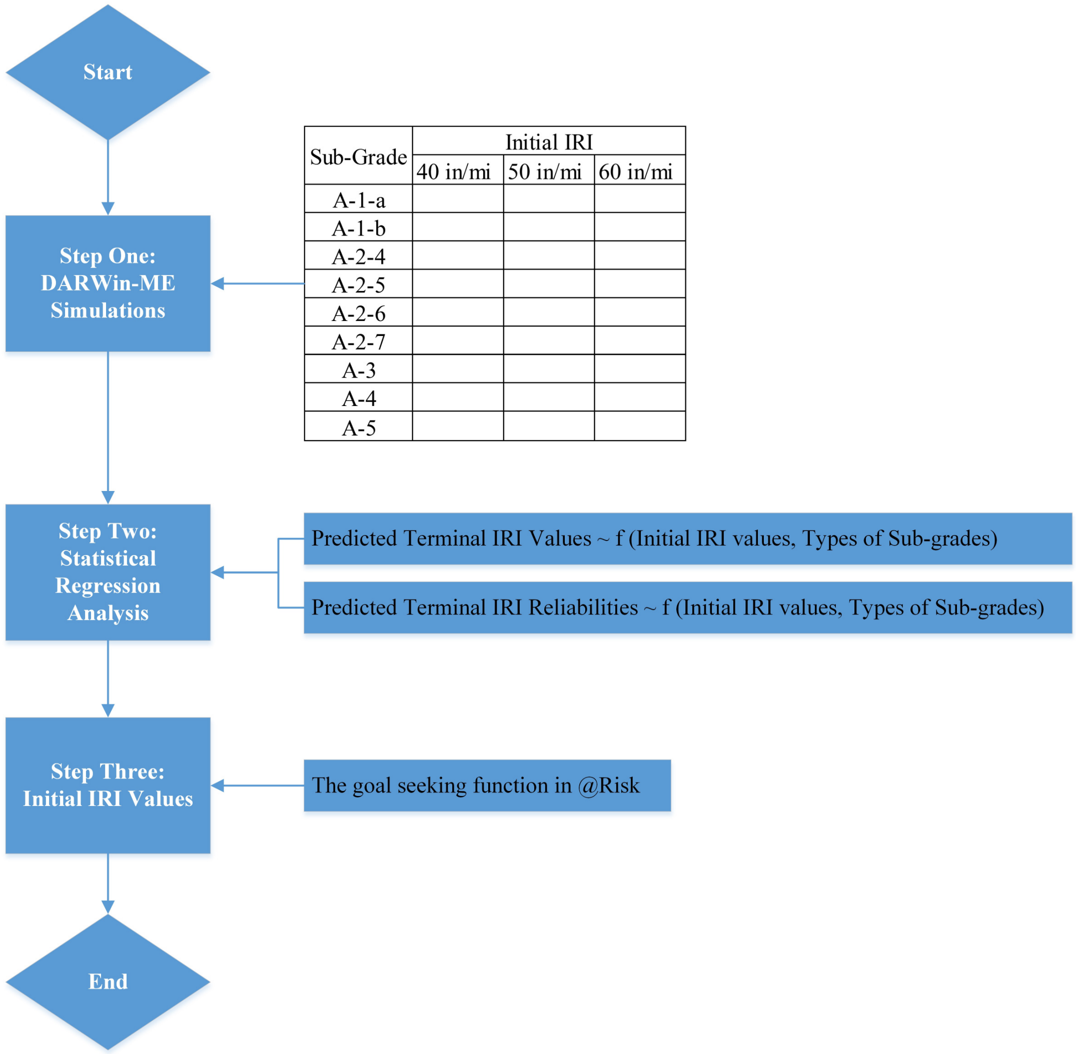
The determination of initial IRI values involved the following three steps:

Step One: Design simulations using the AASHTOWare Pavement ME Design software. In this step, three different initial IRI values (40 in./mi., 50 in./mi., and 60 in./mi.), nine different subgrade types as specified by AASHTO (A-1-a, A-1-b, A-2-4, A-2-5, A-2-6, A-2-7, A-3, A-4, and A-5) [12], a sub-base of 8” of lime, a base of 8” of crushed stone, a sub-surface of 4” of asphalt, and a surface of 3” of asphalt, the North Carolina Charlotte International Airport weather station, and default traffic volumes were used to run design simulations. The target reliability was set as 95%, which is the default value used by the AASHTO design guide [12]. The design life was set to 20 years. A total of 26 predicted terminal IRI values and their corresponding predicted reliabilities were obtained.

Step Two: Statistical analyses using the statistical discovery software JMP. Two regression analyses were conducted. The first was to derive the relationship between predicted terminal IRI reliabilities and initial IRI values as well as types of subgrade, and the second was to derive the relationship between predicted terminal IRI values and initial IRI values as well as types of subgrade.

Step Three: Determination of initial IRI values using the risk analysis tool @Risk. Using the first regression equation obtained in Step Two, and setting the goal of predicted terminal IRI reliability as 95%, the goal seeking function of @Risk was used to determine initial IRI values for different types of subgrade. Then the corresponding terminal IRI values, which can be used to valid reasonableness of initial IRI values, were calculated using the second regression equation.

Figure 1 illustrates the research methodology.



Sub-Grade	Initial IRI		
	40 in/mi	50 in/mi	60 in/mi
A-1-a			
A-1-b			
A-2-4			
A-2-5			
A-2-6			
A-2-7			
A-3			
A-4			
A-5			

Figure 1. Flow chart

Scope of Work

A number of factors can affect a pavement's initial smoothness, such as the pavement's base/subbase support characteristics, the pavement's functional classification, material properties, traffic volume, and climatic conditions. This study selected subgrade as the impact factor because it represents a pavement's support characteristics, and a weak road bed support can cause a poor initial smoothness. Also, flexible pavements were studied in this research. However, these do not impose a limitation on the type of impact factors and pavements that could be used. Instead, the proposed methodology is flexible enough to be applied to other abovementioned factors as well as rigid and composite pavements.

Data Set

Simulation results are reported in Table 1, including the initial IRI values, types of subgrade, and the corresponding terminal reliability and IRI values. A total of 26 observations were obtained. Note that there is missing data due to an error during the reporting process.

Table 1. AASHTOWare pavement ME design simulation results

Initial IRI (in./mi.)	Subgrade	Terminal Reliability (%)	Terminal IRI (in./mi.))
40	A-1-a	99.65	133.15
40	A-1-b	99.60	134.04
40	A-2-4	99.41	137.02
40	A-2-5	99.26	138.89
40	A-2-6	99.07	140.92
40	A-2-7	98.98	141.68
40	A-3	99.70	131.96
40	A-4	98.85	142.82
40	A-5	97.52	151.04
50	A-1-a	98.35	146.43
50	A-1-b	99.60	134.04
50	A-2-4	99.41	137.02
50	A-2-5	99.26	138.89
50	A-2-6	99.07	140.92
50	A-2-7	98.98	141.68
50	A-3	99.70	131.96
50	A-4	91.59	168.73
50	A-5	97.52	151.04
60	A-1-a	95.24	159.46
60	A-1-b	94.95	160.31
60	A-2-4	95.74	157.79
60	A-2-5	93.22	164.95
60	A-2-6	92.41	179.15
60	A-2-7		
60	A-3	95.60	158.32
60	A-4	91.59	168.73
60	A-5	92.08	167.63

Variables

As described in Step Two, two regression analyses were conducted. In the first analysis, the dependent variable is predicted terminal IRI reliabilities, and the independent variables are initial IRI values and types of subgrade. In the second regression analysis, the dependent variable is predicted terminal IRI values, and the independent variables are initial IRI values and types of subgrade.

Results and Discussion

Regression Analysis: Predicted Terminal IRI Reliabilities vs. Initial IRI Values and Types of Subgrade

Statistical graphs (Figures 2 and 3), effect tests (Table 2), the summary of fit (Table 3), and analysis of variance (ANOVA) (Table 4) are shown below.

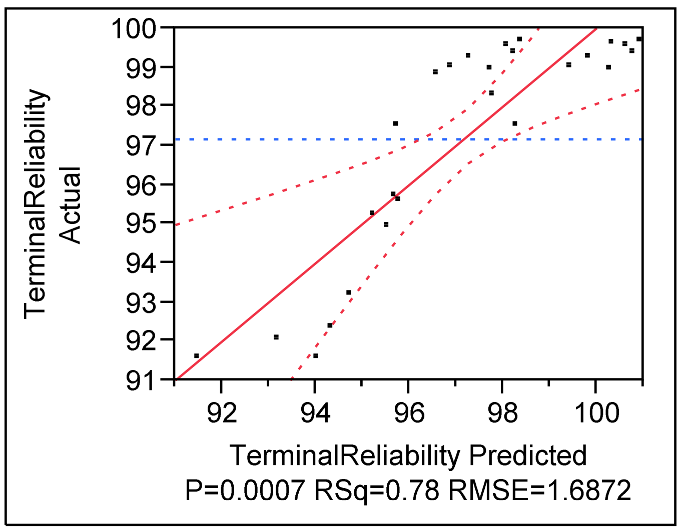


Figure 2. Actual by predicted plot

ISBN 978-1-60643-379-9

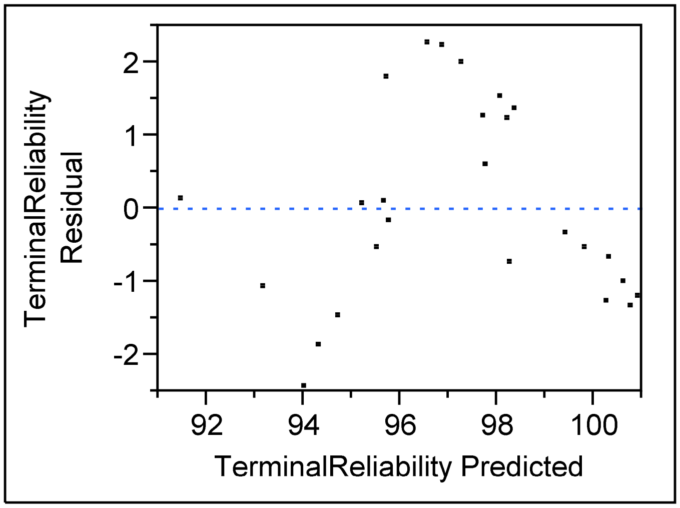


Figure 3. Residual by predicted plot

Table 2. Effect tests

Source	DF	Sum of Squares	F Ratio	Prob > F
Initial IRI	1	108.08321	37.9683	< 0.0001
Subgrade	8	45.46039	2.084	0.1006

Table 3. Regression analysis summary of fit

RSquare	0.780
RSquare Adj	0.657
Root Mean Square Error	1.687
Mean of Response	97.167
Observations	26

Table 4. Analysis of variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	9	161.823	17.980	6.316	0.0007
Error	16	45.547	2.847		
C. Total	25	207.369			

In Figure 2, “terminal reliability actual” are simulation results (column 3 in Table 1). “Terminal reliability predicted” is reliability values predicted by the regression equation. Figure 2 shows that the majority of predicted reliability values fall in the bounds of the 95% confidence curves (red-dotted lines). This indicates that the model is significant. Figure 3 shows that residual values scattered approximately randomly about zero, which means that the model form is appropriate. Table 2 shows results of effect tests on the null hypothesis that all parameters associated with the initial IRI values and subgrade types are zero. The effect of initial IRI is statistically significant. In Table 3, an R-square of 0.780 indicates that 78% of variation in terminal IRI reliabilities can be explained by initial IRI values and subgrade types, which is statistically significant. A p-value of 0.0007 in Table 4 rejects the null hypothesis indicating that the differences observed in terminal IRI reliabilities are not due to random sampling, but due to different initial IRI values and different types of subgrade , and that the actual strength of the relationship is strong. In this analysis, since there are 10 independent variables (9 different types of subgrade and initial IRI), the degree of freedom is 9 (Table 4).

The prediction expression is

$$\begin{aligned}\textit{Terminal IRI Reliability} = {} & 109.889 - 0.256*\textit{InitialIRI} + 0.654*\{\textit{Subgrade[A-1-a]}\} + \\ & 0.958*\{\textit{Subgrade[A-1-b]}\} + 1.094*\{\textit{Subgrade[A-2-4]}\} + \\ & 0.154*\{\textit{Subgrade[A-2-5]}\} - 0.242*\{\textit{Subgrade[A-2-6]}\} + \\ & 0.608*\{\textit{Subgrade[A-2-7]}\} + 1.241*\{\textit{Subgrade[A-3]}\} - \\ & 3.082*\{\textit{Subgrade[A-4]}\}\end{aligned} \tag{1}$$

To understand how to use equation (1), an example is given below:

For subgrade A-1-a, *{Subgrade[A-1-a]}* = 1, and the rest of the indicator variables are 0. Thus its terminal IRI reliability can be written as:

$$\textit{Terminal IRI} = 109.889 - 0.256*\textit{InitialIRI} + 0.654 = 110.543 - 0.256*\textit{InitialIRI}$$

Similarly, for subgrade A-2-4, its terminal IRI reliability can be written as:

$$\textit{Terminal IRI} = 109.889 - 0.256*\textit{InitialIRI} + 1.094 = 110.983 - 0.256*\textit{InitialIRI}$$

In this multiple regression analysis, the coefficient of Initial IRI is a constant, and the intercept varies based on the subgrade type.

Regression Analysis: Predicted Terminal IRI Values vs. Initial IRI Values and Types of Subgrade

Statistical graphs (Figures 4 and 5), effect tests (Table 5), the summary of fit (Table 6), and analysis of variance (ANOVA) (Table 7) are shown below.

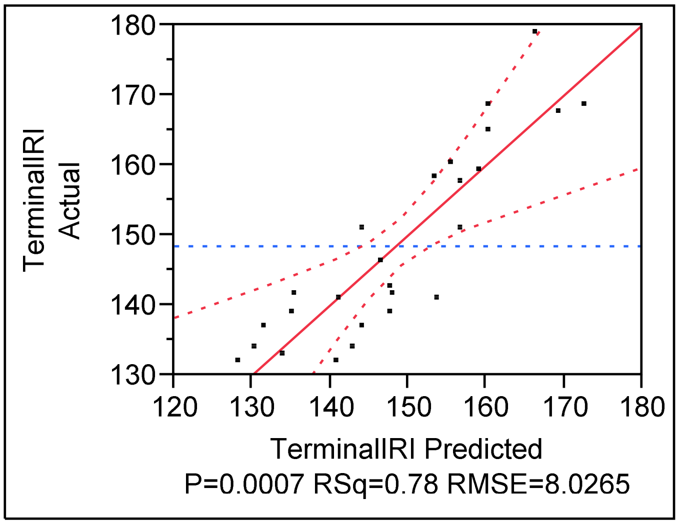


Figure 4. Actual by predicted plot

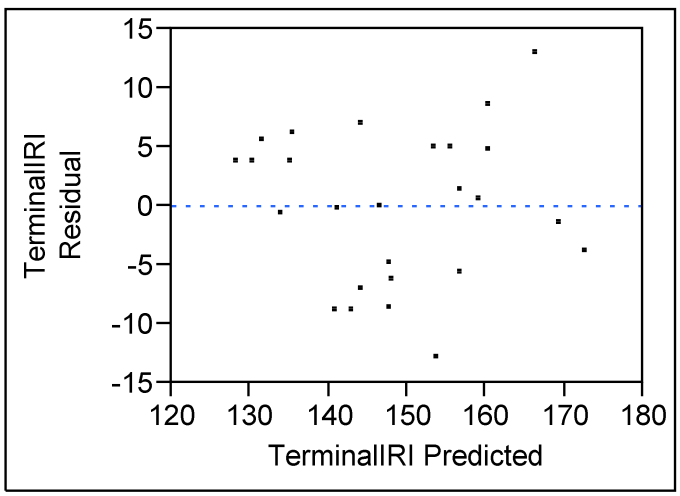


Figure 5. Residual by predicted plot

Table 5. Effect tests

Source	DF	Sum of Squares	F Ratio	Prob > F
Initial IRI	1	2584.3788	40.1151	< 0.0001
Sub-grade	8	1031.9227	2.0022	0.1129

Table 6. Regression analysis summary of fit

RSquare	0.783
RSquare Adj	0.660
Root Mean Square Error	8.026
Mean of Response	148.407
Observations	26

Table 7. Analysis of variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	9	3712.432	412.492	6.403	0.0007
Error	16	1030.785	64.424		
C. Total	25	4743.217			

In Figure 4, "terminal IRI actual" are simulation results (column 4 in Table 1). "Terminal IRI predicted" are IRI values predicted by the regression equation. Figure 4 shows that the majority of predicted IRI values fall in the bounds of the 95% confidence curves (red-dotted lines). This indicates that the model is significant. Figure 5 shows that residual values scattered randomly about zero, which means that the model form is appropriate. Table 5 shows results of effect tests on the null hypothesis that all parameters associated with the initial IRI values and subgrade types are zero. The effect of initial IRI is statistically significant. In Table 6, an R-square of 0.783 indicates that 78.3% of variation in terminal IRI values can be explained by initial IRI values and subgrade types, which is statistically significant. A p-value of 0.0007 in Table 4 rejects the null hypothesis indicating that the differences observed in terminal IRI values are not due to random sampling, but due to different initial IRI values and different types of subgrade , and that the actual strength of the relationship is strong.

The prediction expression is

$$\begin{aligned} \textit{Terminal IRI} = {} & 86.277 + 1.252 * \textit{InitialIRI} - 2.506 * \{\textit{Subgrade[A-1-a]}\} - \\ & 6.056 * \{\textit{Subgrade[A-1-b]}\} - 4.909 * \{\textit{Subgrade[A-2-4]}\} - \\ & 1.276 * \{\textit{Subgrade[A-2-5]}\} + 4.811 * \{\textit{Subgrade[A-2-6]}\} - \\ & 0.915 * \{\textit{Subgrade[A-2-7]}\} - 8.106 * \{\textit{Subgrade[A-3]}\} + \\ & 11.241 * \{\textit{Subgrade[A-4]}\} \end{aligned} \tag{2}$$

At 95% terminal IRI reliability, initial IRI, and terminal IRI values for 9 different types of subgrades were calculated using equations 1 and 2, and the goal seeking function of @Risk program. The results are summarized in Table 8.

Table 8. Initial and terminal IRI values for 95% terminal reliability

	Initial IRI (in/mi)	Terminal IRI (in/mi)
Subgrade [A-1-a]	63	163
Subgrade [A-1-b]	63	159
Subgrade [A-2-4]	63	160
Subgrade [A-2-5]	57	156
Subgrade [A-2-6]	55	160
Subgrade [A-2-7]	63	164
Subgrade [A-3]	63	157
Subgrade [A-4]	49	158
Average	60	160

Discussion

In 2013, a study [13] was conducted to evaluate public perception of the smoothness of pavements in North Carolina. The results indicate that an IRI rating of 156 in./mi. is the threshold for driving public rate roadway ride quality as either acceptable or unacceptable. The average terminal IRI value obtained from this study is 160 in./mi. (Table 8), which is fairly close to this threshold. Therefore, it can be concluded that the results from this study are reasonable.

The results in Table 8 also indicate that for a pavement that is located in Charlotte North Carolina, designed to have a sub-base of 8" of lime, a base of 8" of crushed stone, a sub-surface of 4" of asphalt, and a surface of 3" of asphalt, while carrying typical traffic volumes, and has either one of 9 subgrade types, its average initial IRI value should be 60 in./mi.

In this study, three initial IRI values and nine types of subgrade were considered in statistical analyses. However, the same methodology can be easily applied to pavements that have different designs, including more initial IRI values variables, various thicknesses, and materials of sub-base, base, sub-surface, and surface, differing weather stations as well as traffic volumes, and to different types of pavements, such as rigid and composite pavements.

Conclusions and Recommendations

Previous research has stated that three factors affect pavement roughness: environmental, material behavior, and traffic volume [14]. However, there has been limited research that includes all this data in computer simulated models. This study was conducted to bridge this gap in knowledge. Initial IRI values for different flexible pavement designs were derived as acceptance criteria using AASHTOWare Pavement ME Design simulations. The results have been validated to be robust. The contributions of this study are twofold: developing IRI acceptance values for new roadway pavement using simulated models would allow state highway administrations (SHA)to have a QC/QA based on initial IRI values, and this also would provide contractors with a way to evaluate their work before presenting their completed projects to the SHAs. Once implemented, the proposed methodology can be applied to rigid and composite pavements that have different designs.

For future studies, it is recommended to conduct sensitivity analysis to identify the most important factors among pavement materials, thicknesses, weather stations, and traffic volumes that impact terminal IRI values and reliabilities, and to use model selection techniques (stepwise, forward, or backward) to develop the final optimum models.

References

[1] Kohn, S. D., Perera, R. W., Cable, J. K., Karamihas, S. M., & Swanlund, M. (2008). Use of Profile Data to Detect Concrete Paving Problems. *9th International Conference on Concrete Pavements: The Golden Gate to Tomorrow's Concrete Pavements*, 690-703.

[2] Titi, H., & Rasoulian, M. (2008). Evaluation of Smoothness of Louisiana Pavements Based on International Roughness Index and Ride Number. *Jordan Journal of Civil Engineering*, *2*(3), 238-249.

[3] Butts, N., & Ksaibati, K. (2003). Asphalt Pavement Quality Control/Quality Assurance Programs in the United States. *Annual Meeting of the Transportation Research Board*.

[4] Stroup-Gardiner, M., Carter, A., Das, T., & Bowman, B. (2005). Part 5: Hot-Mix Asphalt Pavement: Initial Ride Quality of Hot-Mix Asphalt Pavements. *Transportation Research Record*, *1907*(1), 105-112. doi: 10.3141/1907-12.

[5] Thebeau, D., Delisle, M.-C., & Cormier, B. (2005). Quebec's Experience with Smoothness Specifications on Concrete Pavements. *Innovations for Concrete Pavement: Technology Transfer for the Next Generation*, *2*, 718-732.

[6] Ningyuan, L., Quin, R., & Liu, Z. (2013). Performance Measures and Evaluation of Asphalt Pavements Using the International Roughness Index. *First International Symposium on Pavement and Geotechnical Engineering for Transportation Infrastructure*, 19-30. doi: 10.1061/9780784412817.002 .

[7] Chatti, K., Manik,A., & Imen, Z. (2011). *Assessment of Pavement Acceptance Criteria and Quantifying its As-Constructed Material and Structural Properties*. Michigan Department of Transportation.

[8] Corley-Lay, J., & Mastin, N. (2009). *Evaluation of Long-Term Pavement Performance Profile Data for Flexible Pavements*. Transportation Research Record 2093. Washington, D.C.: Transportation Research Board, 25-30.

[9] Hand, A., Mondal, A. &Ward, D. (2001). A Performance Evaluation of Lightweight Non-Contact Pavement Profilers. *Journal of Testing and Evaluation*, *29*(2), 161-172.

[10] Wix, R. (2003). Ride Quality Specifications —Smoothing Out Pavements. *Proceedings of the Conference of the Australian Road Research Board*, *21*, 549-565.

[11] El-Korchi,T., & Collura, J. (1998). Comparative study of Ride Quality Measuring Devices. *Transportation Research Record*, *1643*, 125-135.

[12] AASHTO. (2008). *Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice*. Washington, D.C.: AASHTO.

[13] Chen, D., Hildreth, J., & Nicholas, T. (to be published). *Development of IRI Limits and Targets for Network Management and Construction Approval Purposes*. Final Report.

[14] Chen, I-C. C.(2009). A Study on the Incentive/Disincentive Schemes of Expressway Pavement Smoothness. *Journal of the Chinese Institute of Civil & Hydraulic Engineering*, *2*(2), 137-153.

Biographies

DON CHEN is currently an assistant professor in the Department of Engineering Technology and Construction Management at University of North Carolina at Charlotte (UNC Charlotte). He has extensive experience in pavement management systems and has over 22 years of experience as an engineer, researcher, and educator. He is a LEED AP since 2009. Dr. Chen may be reached at dchen9@uncc.edu.

MICHAEL DYE is currently an M.S. student in construction and facilities management in the Department of Engineering Technology and Construction Management at UNC Charlotte. He earned his B.S. degree from UNC Charlotte. Michael is currently working on two research projects under Dr. Don Chen's supervision. One of the projects is to develop IRI limits and targets for network management and construction approval purposes. Michael may be reached at mdye2@uncc.edu.