Research Report
KTC-09-07/FR136-04-4F

KENTUCKY TRANSPORTATION CENTER

HIGHWAY-RAILWAY AT-GRADE CROSSING STRUCTURES: RIDEABILITY MEASUREMENTS AND ASSESSMENTS

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Research Report

KTC-09-07/FR 136-04-4F

Highway-Railway At-Grade Crossings:

Rideability Measurements and Assessments

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ABSTRACT

This report provides two analyses for obtaining a quantitative means of rating the condition of railroad-highway at-grade crossings based on their measured roughness. **Phase One** of this report examined 11 crossings in the Lexington area by use of a laser based inertial profiler from the Kentucky Transportation Cabinet (KYTC) and a Face Rolling Dipstick. **Phase Two** was a continuation of **Phase One** with 26 crossings examined using inertial profilers from both the KYTC and the National Center of Asphalt technology. Objective ratings based on rideability were obtained and wheelpath profiles were measured for each crossing. Several roughness indexes were computed from the measured profiles. A correlation between these indexes and subjective rideability ratings were examined in each study. Analysis of the data showed a tendency of objective ratings to decrease as roughness increases. This study found that highway inertial profilers are not an appropriate tool for determining roughness over short distances such as railroad crossings due to their application for testing of longer distances. It is anticipated that this report will be referenced for future research on this topic.

Keywords: Highway-Railway Crossing Rideability, Highway Inertial Profiler, Face Rolling Dipstick, Roughometer II, Automatic Roadway Analyzer, Rail-Highway At-Grade Crossings

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EXECUTIVE SUMMARY

Rail-highway at-grade crossings that decrease in ride quality prematurely result in increased maintenance and re-habilitation costs for the railway industry and governmental agencies. Track quality and pavement smoothness issues can become major concerns. Track roughness through crossings experienced by railway vehicles is periodically monitored by railroad track geometry test vehicles. This data is used to assess when corrective action is required. However, the highway approach and crossing roughness, experienced by vehicular traffic, is not commonly measured quantitatively. There is no standard measure for the magnitude of crossing roughness experienced by highway vehicles. This report provides two analyses for obtaining a quantitative means of rating the condition of railroad-highway at-grade crossings based on their measured roughness.

Phase One of this report examined 11 crossings in the Lexington area by use of a laser based inertial profiler from the Kentucky Transportation Cabinet and a Face Rolling Dipstick. Several roughness indexes were computed from the profiles measured with the inertial profiler, and the correlation between these indexes and subjective rideability ratings were examined. A qualitative comparison was made between the profiles obtained with the inertial profiler and those obtained with the Rolling Dipstick. Several advantages and disadvantages were noted for both profiling methods. In addition, IRI values for nine of the crossings were calculated using the Roughometer II.

Phase Two of this report examined 26 crossings in the greater Lexington, Kentucky area. Two laser-based highway inertial profilers, one from the Kentucky Transportation Cabinet and one from the National Center of Asphalt technology, were used to obtain wheelpath profiles of the railroad crossings. The profiles were used to compute the International Roughness Index, IRI, statistic for each crossing. In addition, the crossings were rated objectively based on rideability; these ratings were compared to the IRI values obtained from the wheelpath profiles. Analysis of the data showed a tendency of objective ratings to decrease as roughness increases. However, the correlation between the datasets was quite weak.

It was determined that highway inertial profilers tend to place more emphasis on the vertical (geometric) alignment of the crossing as opposed to the condition of the crossing surface itself. This study found that highway inertial profilers are not an appropriate tool for determining roughness over short distances such as railroad crossings due to their application for testing of longer distances. It is anticipated that this report will be referenced for future research on this topic.

CHAPTER 1. INTRODUCTION TO RIDEABILITY MEASUREMENTS AND GUIDELINES

1.1 INTRODUCTION

Railroad-highway at-grade crossings constitute an important component of the transportation infrastructure. Improperly maintained crossings can reduce ride quality and create a liability and safety risk to both highway and railroad traffic. In addition to the safety issues, improperly maintained crossings may also deteriorate at an accelerated rate thus resulting in increased life-cycle costs.

The goal of this report is to obtain a technique that will result in a quantitative measure of railroad-highway grade crossing roughness from the perspective of the highway user. Many state highway agencies measure the roughness or rideability of highway pavements, in order to determine maintenance needs and also to bind contractors to quality assurance clauses. These methods have been extensively researched and standards vary little from state to state. The same cannot be said for railroad-highway crossings; at this time there is no method that quantitatively measures the roughness of a crossing surface from the highway users' perspective.

This report focuses on the techniques that can be used to quantitatively evaluate the rideability of railroad-highway at-grade crossings as experienced by the highway users. While the rideability of highway pavements has been researched extensively and is fairly well standardized, no standardization method exists to quantitatively evaluate rideability in the vicinity of railroad crossings. In general, highway agencies use inertial profiling vehicles to obtain the pavement surface profile in the vehicles wheel path. These profiles are used to produce roughness values that take the form of indexes that have been developed through years of research. The agency creates thresholds of what is adequate roughness for the pavement type and values for new construction as well as minimum value that constitutes a need for maintenance. Traffic volumes along with the roughness index score help agencies determine the maintenance priority and the method of repairing the infrastructure.

1.2 ATTEMPTS TO MEASURE ROUGHNESS

As previously stated there methods are available to quantify the roughness of pavement but no widely accepted method exists to quantitatively give a value to crossing roughness. Several attempts have been made to establish a roughness rating, but none successful enough to develop into a standard practice. AASHTO's recommended practice suggests that data from the impact of railroad crossing be excluded from pavement roughness measurements; however a few states such as Illinois include the readings in order to identify trouble spots (Swiderski, 2007).

1.2.1 Initial Attempt

Phase One research evaluated the rideability of railroad-highway at-grade crossings using three different methods to obtain roughness related data at eleven crossings in the Lexington area. These methods included the KYTC's Inertial Profiler, the Face Rolling Dipstick, and the Roughometer II. The report correlates the results from these methods with results from rideability ratings taken by five people through the same eleven crossings. This relationship is significant due to the fact that roughness indexes should correlate with rideability ratings to ensure consistent results and recommendations.

1.2.2 Follow-Up Attempt

Phase Two research evaluated the rideability of railroad-highway at-grade crossings using two different inertial profilers: the Kentucky Transportation Cabinet and the National Center of Asphalt Technology; to obtain roughness related data at twenty-six crossings in the Lexington area. This report also correlated the results from these methods with results from rideability ratings taken by eight individuals through the same twenty-six crossings.

1.2.3 Indiana Department of Transportation Attempt

In January 2003, the Indiana Department of Transportation (INDOT) finalized a report on a study they were conducting on railroad-highway grade crossings. The objective of their research was "to determine if roughness data on railroad crossings could be extracted from INDOT's road network database in order to determine the need and priority of repair projects." (Williams, 2003) INDOT's research hoped to create a Railroad Crossing Index (RCI) that would set a guideline for determining the roughness of a railroad crossing and set a basis for when they were in need of repair. Their research also hoped to achieve correlating the roughness to the general public's perception by using a panel rating method.

INDOT used four different methods when trying to determine the RCI:

1. The first proposed method for generating RCI equates IRI and RCI. By this method the user would specify the distance over which the RCI (IRI) is calculated, from ten feet to 1/10 mile, centered on the crossing.

2. The second proposed method for generating RCI was to calculate a difference in IRIs. This was to be done by generating an IRI for a section of road, including the railroad crossing data, and then use the same raw data to generate a second IRI after "masking out" the railroad crossing data, and take the difference of the two.

3. The third method proposed for calculating RCI is similar to method one, but does not result in a standard IRI number. In addition to enabling the user to specify the distance over which the RCI is calculated (method 1), the user may also specify the 'long wave' parameter used in the IRI calculation.

4. The final method proposed for generating RCI uses a calculated elevation profile. The RCI is the summation of the absolute values of the change in height from a reference index and a moving average of data points surrounding the point under consideration.

After researching and analyzing the data from the trials, the methods above were performed and determined inconclusive due to data being unrecognizable when graphed and could not meet the requirements for the predicted probability of acceptable/unacceptable roughness when calculating the RCI. INDOT also concluded that it would be nearly impossible to distinguish the roughness of the approaches from the roughness due to the rails and railway roadbed (Williams, 2003).

1.3 GUIDELINES FOR CROSSING PROFILES

Recommended practices that are used as guides to establish policies and practices for the profile and alignment of crossings and approaches have been established through The American

Railway Engineering and Maintenance-of-Way Association (AREMA, 2002) as well as the American Association of State Highway and Transportation Officials (AASHTO, 2001). These standards establish a consistent design for railroad/highway grade crossings and approaches and help to eliminate roughness through a crossing, which directly reduces problems such as wear and tear or vehicle hang-up and high centering. The guidelines for the profile and alignment of crossings and approaches states that when a crossing involves two or more tracks, the highway must be level with the top of rails for 2 feet outside of the rails (Swiderski, 2007). Additionally, the surface of the highway cannot be more than 3 inches higher or 6 inches lower than the top of nearest rail at a point 30 feet from the rail, measured at right angle thereto, unless track super-elevation dictates otherwise (Swiderski, 2007). Figure 1.3 illustrates these specifications.

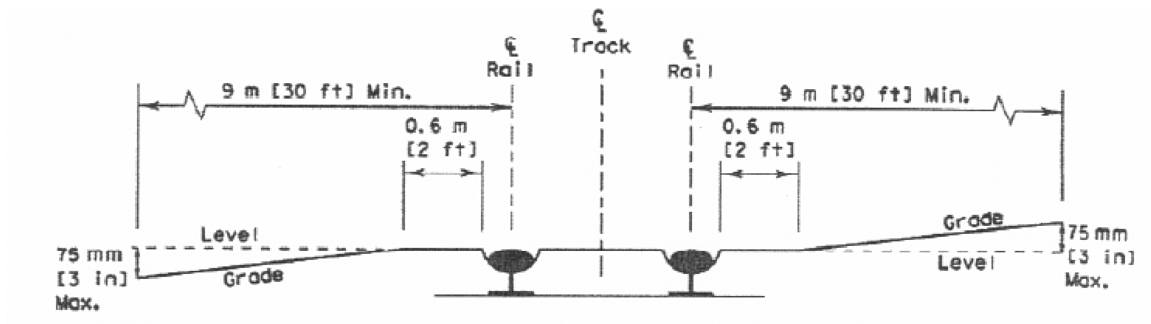

Figure 1.3 Railroad-Highway Grade Crossing (AASHTO, 2001)

1.4 CROSSING ROUGHNESS

Roughness of a crossing is often times confused with the roughness which is caused from the skew of the crossing, the type of vehicle or the crossing approaches. Additionally, if the crossing is in a location such as a curve in the track, the track's super-elevation causes additional roughness which is not representative of the crossing rideability. The problem is compounded if both the railroad and highway contain super-elevation, particularly if the super-elevations are opposite one another (Swiderski, 2007). Regular track maintenance such as track raise could result in a "humped" profile, possibly resulting in a high-profile crossing after successive track raises (Swiderski, 2007). Conversely, highway maintenance such as repaving approaches places the crossing in a depression along the railroad. Due to all of these contributing factors, often times the crossing surface is not the cause of the poor rideability the driver experiences. However, due to topography or other limitations, contributing issues such as a crossing on a skew or curve cannot be avoided (Swiderski, 2007). In order to eliminate as many of these adverse impacts as possibly, a 90-degree intersection is desirable and should be made as level as possible from the standpoint of sight distance, rideability, braking and acceleration distances.

As mentioned previously, crossing roughness is predicted to decrease the safety of the driver and passengers as the vehicle traverses the crossing. In addition to providing a smoother crossing a 90-degree intersection enhances the driver's view of the crossings and allows the drivers attention to be directed to looking for a train rather than negotiating the curve (Swiderski, 2007). One other unsafe consequence of a rough crossing surface is the possibility of vehicle hang-up. Low-clearance vehicles, pose the greatest risk of becoming immobilized at highway-rail grade crossings due to contact with the track or highway surface (Swiderski, 2007). This problem is especially an issue where the crossing is in a sag vertical curve (Swiderski, 2007).

1.5 STANDARDS FOR MEASURING ROUGHNESS

Currently there are no widely used measures for quantitatively measuring roughness through a crossing. However there are standards to measure roughness on highway pavements. Roughness is defined by AASHTO as the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality (Swiderski, 2007). A standard scale of pavement roughness is known as the international roughness index (IRI). This scale was developed by the World Bank in the 1980's in order to create a consistent method of determining pavement roughness that could be utilized worldwide. IRI is calculated from a single longitudinal profile measured with a road profiler in both the inside and outside wheel-paths of the pavement. The average of these two IRI statistics is reported as the roughness of the pavement section (Swiderski, 2007). The recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m) and is based on the accumulated suspension (in., mm) divided by the traveled distance (mi/km).

As seen in Figure 1.5 the IRI roughness scale, lower speed correlates with rougher pavements. Additionally, rougher pavement, such as an unpaved road correlates with a higher IRI value.

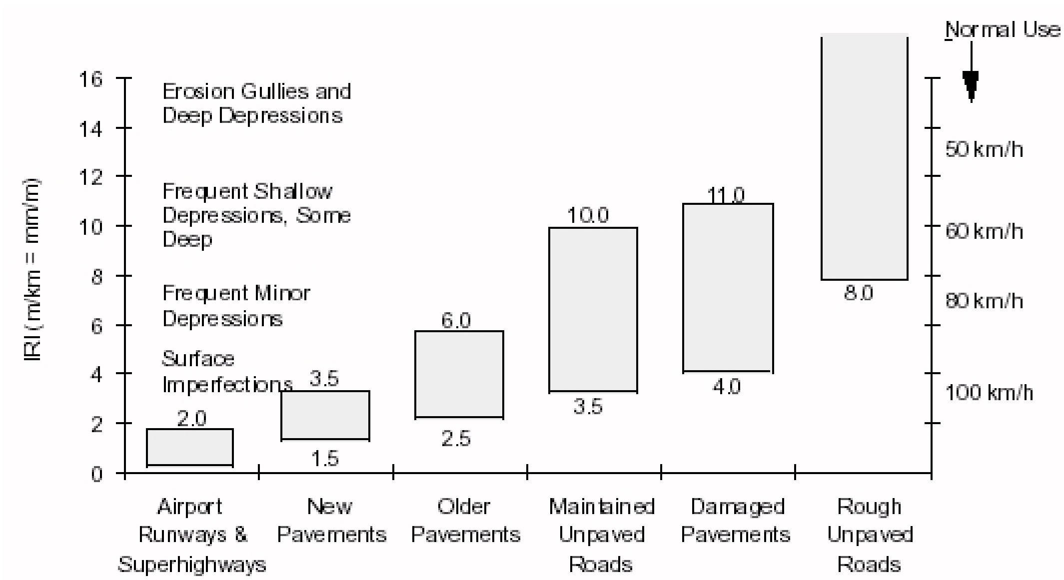

Figure 1.5 IRI Roughness Scale (Sayers, et al., 1986)

The Kentucky Transportation Cabinet's (KYTC) pavement management program quantifies ride quality by IRI as mentioned above. However, since 1960 the quality of Kentucky's pavement has been reported in terms of Rideability Index (RI) which is a conversion from the IRI index (Swiderski, 2007). This scale ranges from zero to five where zero indicates pavement that is too rough to be traveled and five refers to pavement which is in perfect condition (Swiderski, 2007).

The following pavement characteristics are taken into consideration during KYTC's analysis: visual evaluation, ride quality and traffic volume, yearly decrease in ride quality, rutting, travel speed, and skid resistance (Swiderski, 2007). Once the roadway has received an RI score, the pavements are evaluated and priority ranked. The evaluation and ranking include factors such as: condition evaluation, severity of rutting, increase in deterioration with time, and results of deflection testing (Swiderski, 2007). Once the priority list has been created, estimates for corrective actions are developed followed by allocation of funding.

1.6 RIDEABILITY

The objective of this report is to investigate the correlation between rideability and roughness indexes developed from the corresponding wheel-path profiles. When traveling over a pavement, people are sensitive to the frequency, rather than the wavelength, at which oscillations occur. The frequency at which profile features at a certain wavelength are transmitted to the vehicle can be obtained by simply multiplying the wavelength by the vehicle speed. However, the frequency at which passengers in the vehicle experience these features is a function of how the vehicle suspension system responds to the oscillations. The suspension system also alters the magnitude of the oscillations. Therefore, the ride quality experienced by passengers in a vehicle traveling over a given surface will depend on the characteristics of their vehicle, including the suspension system, tires, loading situation, and speed. Rideability is also a subjective quantity and will depend on the perceptions and attitudes of the individual passenger. Therefore, to obtain meaningful results, it is necessary to obtain rideability ratings from several individuals for a given crossing.

Choosing an appropriate analysis speed is one factor that must be considered. To gain insight into the relationship between speed and rideability, data in a Pennsylvania Department of Transportation study of railroad-highway at-grade crossings were examined. As part of this study, crossings were rated by two engineers on a scale of one to ten, with one being the worst and ten being the best rideability. Each crossing was rated at 25 miles per hour. For crossings where the posted speed limit was greater than 25 miles per hour, ratings were also obtained at the speed limit. The results of this portion of the study are presented Tables 1.6a and 1.6b.

Table 1.6a Rideability ratings from Pennsylvania D.O.T. study at 25 miles per hour (Ramirez, 1991)

Type	District	County	SR	Seg.	NB/EB Rating @ 25 MPH	SB/WB Rating @ 25 MPH
Goodyear	3-0	Columbia	0011	0421	N/A*	9.0
Goodyear	8-0	York	Philadelphia St.		N/A*	9.0
Cobra-X	10-0	Armstrong	4023	0070	7.5	7.0
Goodyear	3-0	Columbia	0011	0420	7.5	N/A*
Parkco	11-0	Allegheny	0051	0161	7.0	6.0
Parkco	8-0	York	0030	0161	6.5	5.0
Red Hawk	10-0	Butler	0268	0130	6.0	6.0
Gen-Trac	10-0	Armstrong	0068	0020	6.0	6.0
Goodyear	3-0	Tioga	0287	0400	6.0	7.5
Gen-Trac	8-0	York	0116	0240	5.5	5.5
Gen-Trac	9-0	Somerset	0031	0240	4.5	3.5
Parkco	10-0	Jefferson	0119	0130	4.0	3.5
Gen-Trac	8-0	York	0094	0150	4.0	4.5
Goodyear	2-0	Clearfield	0219	0871	4.0	5.5
Omni	6-0	Delaware	2005	0010	3.5	2.5
Cobra-X	10-0	Jefferson	0219	0200	3.0	3.5
T & A	8-0	Cumberland	2025	0020	2.0	3.0
Parkco	8-0	York	0094	0160	2.0	6.5

* The SR carried traffic in only one direction.

Table 1.6b Rideability ratings from Pennsylvania D.O.T. study at posted speed limit (Ramirez, 1991)

Type	District	County	SR	Seg.	Posted Speed	NB/EB Rating @ Posted Speed	SB/WB Rating @ Posted Speed
Goodyear	3-0	Tioga	0287	0400	55	8.5	8.0
Gen-Trac	10-0	Armstrong	0068	0020	45	8.5	6.5
Parkco	11-0	Allegheny	0051	0161	40	8.0	7.0
Goodyear	3-0	Columbia	0011	0420	25	7.5	N/A**
Parkco	8-0	York	0030	0161	40	6.5	7.5
Gen-Trac	8-0	York	0116	0240	25	5.5	5.5
Gen-Trac	8-0	York	0094	0150	25	4.0	4.5
Parkco	10-0	Jefferson	0119	0130	25	4.0	3.5
Red Hawk	10-0	Butler	0268	0130	35	4.0	7.0
Omni	6-0	Delaware	2005	0010	25	3.5	2.5
Cobra-X	10-0	Jefferson	0219	0200	35	3.0	5.0
T & A	8-0	Cumberland	2025	0020	40	2.5	3.0
Parkco	8-0	York	0094	0160	25	2.0	6.5
Goodyear	2-0	Clearfield	0219	0871	35	N/A*	N/A*
Gen-Trac	9-0	Somerset	0031	0240	35	N/A*	4.5
Cobra-X/Omni	10-0	Armstrong	4023	0070	N/A	N/A*	N/A*
Goodyear	3-0	Columbia	0011	0421	35	N/A**	8.5
Goodyear	8-0	York	Philadelphia	St.	25	N/A**	9.0

*Posted speed could not be maintained over crossing due to an adjacent turn.

** The SR carried traffic in only one direction.

The rideability ratings at 25 miles per hour were matched with the rideability ratings at the posted speed limit for each crossing with complete data. Crossings with data available for two separate directions were treated as two separate crossings. For each crossing, the change in speed (defined as speed limit minus 25 miles per hour) and the change in rideability (defined as rideability at speed limit minus rideability at 25 miles per hour) were calculated. The results are presented in Figure 1.6a, where the line passes through the mean change in rideability at each level of change in speed. On average, the rideability ratings increased as speed increased. For a change in speed of 10 miles per hour, the rideability ratings of two crossings decreased, the rideability ratings of two other crossings increased, and the rideability of the fifth crossing remained the same. For crossings where the change in speed was greater than 10 miles per hour, the rideability rating of each crossing either increased or remained the same. For the crossings in this study, the magnitude of the change in rideability was as high as 2.5, which is significant when the rideability is measured on a scale of one to ten.

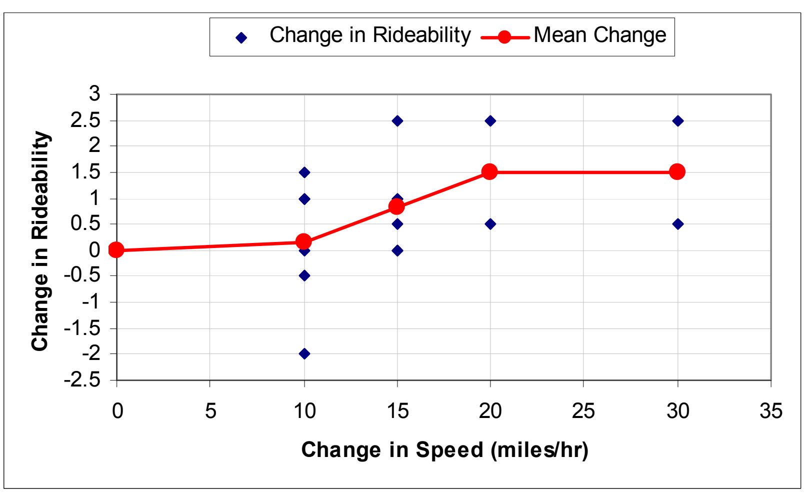

Figure 1.6a Variation of rideability with speed for crossings in Pennsylvania D.O.T. study

It should be noted that the crossings considered in the Pennsylvania D.O.T. study generally did not include steep approaches that would create a noticeably humped profile. For crossings where the approaches create a noticeably humped profile, with sudden grade changes, it can be hypothesized that rideability would actually decrease with increases in speed. Crossings of this type can also cause a vehicle to become airborne at high speeds, resulting in a very dangerous situation.

Based on these considerations, a standard speed of 25 miles per hour was selected for obtaining the rideability ratings. All of the crossings in this study could be safely crossed at this speed. This speed was also considered to be fairly representative of actual vehicle speeds at most crossings of the crossings, since drivers will normally slow down somewhat as they approach a crossing. Some very smooth crossings on busy roads, such as the Versailles Bypass, normally carry traffic at higher speeds, but this issue will not be addressed further in this report. Following the example of the Pennsylvania study, it was decided to rate crossing rideability on a scale of one to ten. This rating scale is presented in Figure 1.6b.

Rating Scale	
10 9	Very Good
8 7	Good
6 5	Fair
4 3	Poor
2 1	Very Poor

Figure 1.6b Scale used to Obtain rideability ratings

CHAPTER 2. PROFILING METHODS

Several methods were employed to develop a Railroad-Crossing profile. **Phase One** used a Face Rolling Dipstick, the Kentucky Transportation Cabinet Inertial Profiler that is used for similar highway applications, and the Roughometer II which is a vehicle attachment that is used to quantify road roughness. **Phase Two** used the KYTC Inertial Profiler and additionally the ARAN inertial profiler from the National Center for Asphalt Technology.

2.1 FACE ROLLING DIPSTICK

The Rolling Dipstick operates by simply rolling the dipstick along the surface of interest. The device consists of three collinear wheels. The two outer wheels are used to establish a reference line, and displacement of the center wheel from this reference line, which is called the trace, is recorded at one-inch intervals. From this data, elevations relative to the starting point can be calculated. The Rolling Dipstick enables profiles to be measured at walking speed (up to three miles per hour). It would not be practical to profile an entire highway network at walking speed, but railroad crossings occupy a very small percentage of the overall highway network, and therefore it would not be particularly inconvenient to use the Rolling Dipstick for this purpose.

A few roughness indexes, including the International Roughness Index, can be calculated on-site using the Dipstick's computer. Data can also be transferred to a desktop computer for further processing with the software that is included with the Rolling Dipstick; however, this software is outdated and is somewhat limited in its profile analysis capabilities. Even with these pitfalls the software can be used to generate a text file containing the measured elevations at one-inch intervals. It should be possible to convert this data into a format that could be read by more sophisticated profile analysis packages.

One major advantage of the Rolling Dipstick is the fact that it rolls along the pavement surface. Since only points on the pavement that come into contact with a vehicle tire actually have an effect on the ride quality experienced by persons traveling in that vehicle, there is no need to include points that are not touched by vehicle tires in the analysis. In fact, it is undesirable to include such points in the analysis since they will affect roughness indexes but not rideability, resulting in poor correlation between the two. This is an issue not only with respect to railroad crossing rideability, but also with respect to the rideability evaluations of standard highway pavements. As a result, research is underway to develop a tire-bridging computer algorithm to automatically remove this type of point from the analysis. The Rolling Dipstick may provide a suitable alternative to such an algorithm.

2.2 ROUGHOMETER II

The Roughometer II is a device distributed by Humboldt for quantifying road roughness. It can be installed on an ordinary passenger vehicle and uses an accelerometer to measure the deflection of the left side of the vehicle's rear axle. Speed and distance traveled are also recorded, and IRI is computed directly from these measurements. The user specifies the distance of the intervals over which IRI is to be calculated. The main advantages of this device appear to be its relatively low cost and ease of use. Also, since the device does not measure the pavement surface directly, points on the surface that are irrelevant to ride quality will not be an issue.

There is a lower speed limit of approximately 25 miles per hour for taking measurements with this device.

2.3 INERTIAL PROFILERS

Inertial Profilers are the most common method of obtaining highway profiles nationwide and they have many advantages over other methods. Primarily these vehicles are used because they can be operated at highway speeds meaning quick obtainment of data and safety for the operators and highway users alike.

In their most basic form, inertial profilers work by combining three elements: a reference elevation datum, a height relative to the elevation datum, and longitudinal distance. In order to obtain these measurements, inertial profilers use a height measuring device, accelerometer, an onboard computer, and a longitudinal distance measuring device. An accelerometer is a device that measures acceleration, in the case of an inertial profiler the accelerometer measures vertical acceleration. Algorithms convert this vertical acceleration measure into a vertical datum by taking the double integral of the vertical acceleration. This vertical datum is the height of the accelerometer in the vehicle in which it is mounted. A vertical measuring device is then used to measure the distance from the vertical datum to the pavement surface. In general, inertial profilers use a static laser to measure this distance. The pavement profile is calculated by taking the difference of the inertial datum and the measured distance from the lasers. The longitudinal distance is measured using the vehicles speedometer.

2.3.1 KYTC Inertial Profiler

Similar to the standard inertial profiler this device uses two static lasers in each wheel path to measure the distance from the inertial datum provided by onboard accelerometers to the pavement surface. An internal unit that processes a signal from the braking system uses a coefficient to get actual distance measures. The state uses a 10,560 ft test site to calibrate the distance coefficient. The start and finish of measurement is determined by placing traffic cones with reflective tape at the beginning and end of each run. A third laser on the vehicle projects a horizontal beam to the side of the vehicle and when the laser intercepts the reflective tape, the vehicle begins measurement. The vehicle terminates measurement when the laser intersects the second cone with reflective tape.

The KYTC vehicle has a minimum measurement distance of 200 feet, therefore the first road cone must be placed 100 feet upstream of the crossing and 100 feet downstream of the crossing and the second 100 feet passed the railroad crossing. This profiler also has a minimum speed of 20 miles per hour while taken measurements and is able to take measurements up to posted highway speeds.

2.3.2 NCAT ARAN Inertial Profiler

Auburn University's National Center for Asphalt Technology (NCAT) Automated Roadway Analyzer (ARAN) is much like the KYTC and standard profilers. The ARAN Van uses two static lasers mounted in front of the vehicle to measure the distance to the pavement surface from the inertial datum established from the vehicle's on board accelerometers. The right wheel path laser has the ability to sample at a rate where pavement texture can be obtained. In addition, the vehicle has two rear mounted scanning lasers, these measure rut depth in the pavement surface.

The longitudinal distance is measured using a wheel encoder attached to the right-rear wheel; this device measures the rotation of the axle and converts it to the horizontal distance. This vehicle does not have an automated means of acquiring start and stop points for measurements as the KYTC vehicle does. The operator must start and stop points for measurements manually using the on-board computer's keyboard. ARAN also has a minimum measuring distance of 400 feet; therefore the measurements began 200 feet prior to reaching the crossing and 200 feet after passing the railroad crossing. This vehicle has a minimum testing speed of 15 miles per hour and can test up to posted highway speeds.

CHAPTER 3. PHASE ONE: INITIAL TESTING OF RAILROAD-HIGHWAY AT-GRADE CROSSINGS

3.1 RESEARCH METHODOLOGY

Eleven railroad-highway at-grade crossings were selected for analysis. All of the crossings handled two-way traffic, so at least two sets of wheel-path profiles and two rideability ratings could be obtained for each. Therefore, for the purposes of this report, each direction was treated as a separate crossing. One of the selected crossings handled two lanes of traffic per direction therefore only the two outer lanes were considered. Each crossing was assigned a number between 1 and 11. Descriptions of each crossing location, along with the corresponding crossing number, are provided in Table 3.1.

3.1.1 Objective Ratings

Rideability ratings were obtained according to the rideability section outlined in Chapter 1 of this report (Witt, 2005 Appendix D). Five individuals in two different vehicles obtained ratings for each crossing. The individual ratings were averaged to obtain a mean rating for each crossing. A summary of the rating forms are found in Table 3.1 and this data is represented graphically in Figure 3.1.1; where each point represents an individual rating for a given crossing and the line goes through the mean rating of each crossing. Each directional crossing was assigned a code based on the crossing number and direction of travel in order to simplify crossing identification.

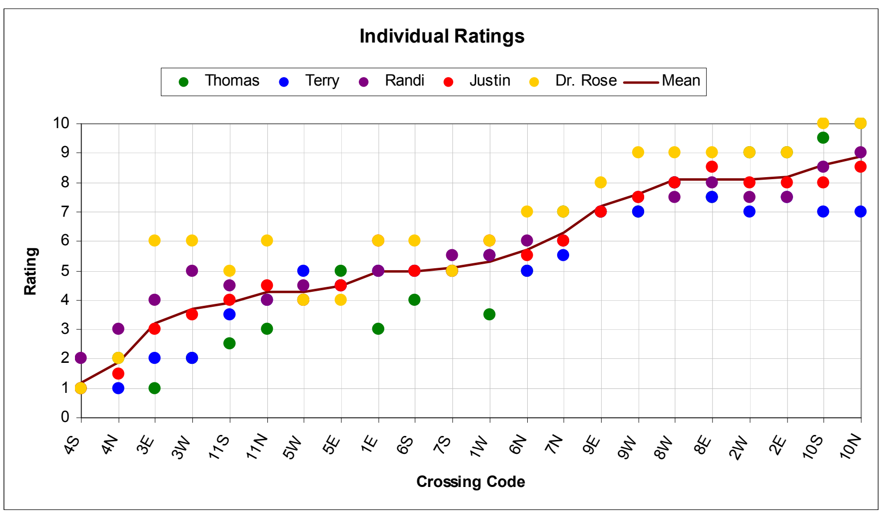

Figure 3.1.1: Ratings for each directional crossing

It was observed that there are essentially two different types of roughness that may affect the rideability of a crossing. One type occurs in the immediate vicinity of the railroad track. This type of roughness is characterized by differential settlement and deterioration of the crossing surface. It is caused by profile features that occur at low wavelengths and leads to relatively low-amplitude, high-frequency oscillation of vehicles traveling over the crossing.

3.1.2 Inertial Profilers

The second type of roughness is characterized by changes in profile slope at the interfaces between the standard highway pavement, the crossing approaches, and the actual crossing

Table 3.1 Phase One Crossing Listing and Ratings for Each Individual Crossing

Crossing Number	Crossing Location	Highway Direction	Crossing Type	Number of Tracks
1	Clifton Road, Versailles	E/W	Timber and Asphalt	1
2	US 60 Bypass, Versailles (East Crossing)	E/W	Concrete	1
3	US 62, Midway	E/W	Rubber Seal and Asphalt	1
4	Yarnallton Road	E/W	Rubber Seal and Asphalt	1
5	Alexandria Drive, Southeast Crossing	E/W	Timber and Asphalt	1
6	Forbes Road (North Crossing)	N/S	Rubber Seal and Asphalt	1
7	Forbes Road (South Crossing)	N/S	Asphalt	1
8	Waller Avenue	E/W	Concrete	2
9	Rosemont Garden	E/W	Concrete	2
10	Main St, Richmond	N/S	Concrete	1
11	Irvine St, Richmond	N/S	Rubber Seal, Timber and Asphalt	2

Crossing			Rating					
Description	Direction	Code	Thomas	Terry	Randi	Justin	Dr Rose	Mean
Yarnallton Road	S	4S	1	1	2	1	1	1.2
Yarnallton Road	N	4N	2	1	3	1.5	2	1.9
Midway	E	3E	1	2	4	3	6	3.2
Midway	W	3W	2	2	5	3.5	6	3.7
Irvine Street	S	11S	2.5	3.5	4.5	4	5	3.9
Irvine Street	N	11N	3	4	4	4.5	6	4.3
Alexandria Drive	W	5W	4	5	4.5	4	4	4.3
Alexandria Drive	E	5E	5	4.5	4.5	4.5	4	4.5
Clifton Road	E	1E	3	5	5	6	6	5
Forbes Road North Crossing	S	6S	4	5	5	5	6	5
Forbes Road South Crossing	S	7S	5	5	5.5	5	5	5.1
Clifton Road	W	1W	3.5	5.5	5.5	6	6	5.3
Forbes Road North Crossing	N	6N	5	5	6	5.5	7	5.7
Forbes Road South Crossing	N	7N	7	5.5	6	6	7	6.3
Rosemont Garden	E	9E	7	7	7	7	8	7.2
Rosemont Garden	W	9W	7	7	7.5	7.5	9	7.6
Waller Avenue	W	8W	8	8	7.5	8	9	8.1
Waller Avenue	E	8E	7.5	7.5	8	8.5	9	8.1
Versailles Bypass	W	2W	9	7	7.5	8	9	8.1
Versailles Bypass	E	2E	9	7.5	7.5	8	9	8.2
Main Street, Richmond	S	10S	9.5	7	8.5	8	10	8.6
Main Street, Richmond	N	10N	10	7	9	8.5	10	8.9

surface. This roughness is only a major factor at crossings that are located on a noticeable hump. This type of roughness is caused by profile features that occur at higher wavelengths and leads to relatively high-amplitude, low-frequency vibration of vehicles traveling over the crossing. After examining the crossings in this study, it was observed that this type of roughness generally occurs within fifty feet upstream of the first rail and fifty feet downstream of the last rail. Therefore, this area was selected as the analysis zone for calculating most of the roughness indexes.

In analyzing the effect of wheel-path profiles on rideability, it would be desirable to determine the effects of each of the two types of roughness individually. If such a determination could be made, this knowledge would be very helpful when considering the need for improvements to a crossing since it would provide a basis for deciding what type of improvements (e.g., rebuilding the approaches or renewing the crossing surface) would be most effective at improving rideability.

Wheel-path profiles were obtained for each direction of each crossing using the Kentucky Transportation Cabinet's Inertial Profiler (Witt, 2005 Appendix B), as shown in Figure 3.1.2a. A traffic cone with reflective tape was placed approximately fifty feet upstream of the first rail of each crossing to trigger the profiler to begin recording data. A second cone was placed approximately two feet upstream of the first rail of each track to trigger the machine to record an event point. It was hoped that this would facilitate location of the track. The setup for a double-track crossing is shown in Figure 3.1.2b. The data collected by the profiler were converted to an .ERD file which could be read by both the RoadRuf and the ProVal profile analysis programs. Unfortunately, in doing so the event points were lost. However, in most cases the tracks could easily be identified from the measured profiles.

Figure 3.1.2a Kentucky Transportation Cabinet's Inertial Profiler

Figure 3.1.2b Setup for a double-track crossing (Irvine Street)

The RoadRuf program was used to plot the measured wheel-path profiles of each directional crossing, except the Midway Westbound crossing. Each RoadRuf plot actually includes two profiles: One for each wheel-path. The first profile for each crossing provides an overall view of the crossing and the approaches approximately fifty feet from the first and last track. The second profile provides a close-up view of the crossing proper. In the case of the Irvine Street crossing, a separate close-up view of the profile is presented for each track since in that case the two tracks were fairly far apart. For the Midway and Yarnallton Road crossings, the very steep approaches caused the limitations of the inertial profiler to be exceeded, and as a result the measured profiles are not correct for these crossings. For the Midway crossing in the westbound direction, the location of the crossing proper could not even be identified, which is why no close-up view is provided for that profile. These crossings were therefore omitted from the analysis.

RoadRuf was then used to calculate several roughness indexes for each wheel-path of each of the remaining directional crossings. After applying a 250-millimeter moving average filter, IRI and PI were both calculated for each wheel-path profile of each directional crossing. These indexes were calculated over an interval starting approximately 50 feet from the first rail and ending approximately 50 feet from the last rail. The average of each index was taken over the left and right wheel-paths for each crossing. For IRI, this average was calculated by summing the values for the left and right wheel-paths and dividing by two. For PI, the average was calculated by summing the squares of the PI for the left and right wheel-paths, dividing by two, and taking the square root of the result. This procedure was required since the PI values were themselves calculated in a root-mean-square fashion. The results of this analysis are presented in Table 3.1.2a.

Table 3.1.2a Calculated IRI and PI values for each directional crossing

Crossing	Mean Rating	IRI Left Wheelpath	IRI Right Wheelpath	Average IRI	PI Left Wheelpath	PI Right Wheelpath	Average PI
1E	5	640	524	582	1193	1003	1102
1W	5.3	489	554	522	803	993	903
2E	8.2	434	779	607	943	1469	1234
2W	8.1	307	487	397	979	858	920
5E	4.5	974	1160	1067	1029	987	1008
5W	4.3	804	1041	923	1200	2025	1664
6N	5.7	1129	985	1057	1192	918	1064
6S	5	847	706	777	1305	1454	1382
7N	6.3	636	707	672	1204	1303	1254
7S	5.1	683	888	786	1232	1242	1237
8E	8.1	529	544	537	1062	1049	1056
8W	8.1	610	825	718	1157	1124	1141
9E	7.2	843	984	914	991	1355	1187
9W	7.6	720	786	753	913	1105	1014
10N	8.9	598	778	688	1081	1119	1100
10S	8.6	680	530	605	923	571	767
11N	4.3	1289	1331	1310	1606	1423	1517
11S	3.9	1234	1217	1226	1383	1351	1367

It was hypothesized that profile features occurring at relatively short wavelengths might have more of an effect on rideability at railroad crossings than on standard pavements. To analyze the effect of this type of roughness, a Butterworth filter with lower and upper wavelength cutoffs of 1 foot and 4 feet, respectively, was applied to the area in which the railroad and the highway overlap; this area is referred to as the crossing proper. Defining the location of the crossing proper was one issue that had to be addressed. To achieve some level of standardization, it was felt that, for the purposes of this analysis, the crossing proper should occupy the same length at each crossing. It was also considered important for the crossing proper to include the entire zone where most of the roughness of interest was concentrated. To satisfy these constraints, the beginning and end points of the zone of interest were identified for each crossing from the wheel-path profiles. It was found that the maximum distance between the beginning and end points was twenty feet, so this distance was defined as the length of the analysis zone for the Butterworth filter. The midpoint of the analysis zone for each profile was calculated from the previously defined start and end points. New start and end points were then calculated by adding and subtracting ten feet from the midpoint. The start and end points for each crossing are shown in Table 3.1.2. Note that double-track crossings have two separate analysis zones. The Butterworth filter was applied to the analysis zones for each crossing by specifying a startup distance equal to the start point and a print interval of twenty feet. A roughness index (Butterworth Index, or BWI) was computed from each filtered profile by summing the absolute values of the deviations and dividing the resulting quantity by the analysis length. The average BWI over the left and right wheel-paths and the first and second track, if applicable, was also calculated. The RoadRuf output results are summarized in Table 3.1.2b.

Table 3.1.2b Butterworth Indexes calculated for each directional crossing

Crossing	BWI Track 1 Left Wheelpath	BWI Track 1 Right Wheelpath	BWI Track 2 Left Wheelpath	BWI Track 2, Right Wheelpath	Average BWI
1E	1807	1981			1894
1W	1736	2082			1909
2E	1720	2425			2073
2W	1681	1394			1538
5E	1351	1278			1315
5W	1428	2956			2192
6N	2030	1948			1989
6S	2259	2182			2221
7N	1781	2091			1936
7S	1685	1519			1602
8E	1613	1569	1725	1451	1590
8W	1421	1471	1560	1692	1536
9E	1688	1623	1939	2045	1824
9W	1480	1533	1985	1992	1748
10N	1721	1439			1580
10S	1232	880			1056
11N	2137	2006	2008	1971	2031
11S	2283	1923	2276	2153	2159

3.1.3 Face Rolling Dipstick

Profile data were also collected using the Face Rolling Dipstick (Witt, 2005 Appendix D) as shown in Figure 3.1.3a. Data were collected beginning approximately fifty feet upstream of the first rail and ending approximately fifty feet downstream of the last rail. The data were stored in a separate directory for each crossing. For example, data from Crossing 4 (Yarnallton Road)

Figure 3.1.3a Face Rolling Dipstick

were stored in a directory called Cross4. Data for each wheel-path profile were stored in a file in the appropriate crossing directory. For example, the filename “WR” would indicate that the file contains data for the right-hand profile in the westbound lane. IRI was calculated from each wheel-path profile using the software that was included with the Rolling Dipstick. The interface used for analyzing data with this program is shown in Figure 3.1.3b. It is important to note that by default the program attempts to remove the overall slope from a profile. It does this by effectively rotating the measured profile about an axis perpendicular to the vertical plane in which the wheel-path profile was measured. This does not affect the calculated IRI value, but it does affect the appearance of the profile. To change the elevations back to their original values, go to the “Edit” menu and click “Header.” The “Run Header” screen should appear as shown in Figure 3.1.3c. Set the number in the “Slope” field to zero.

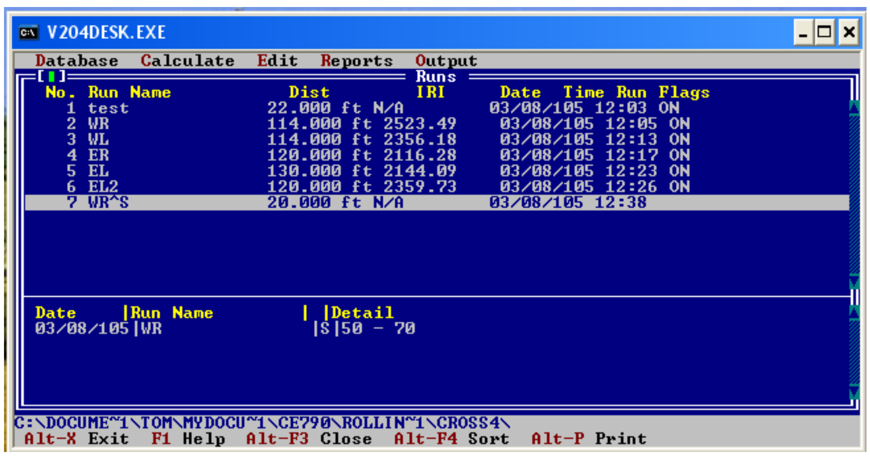

Figure 3.1.3b Interface for profile analysis with the Rolling Dipstick software

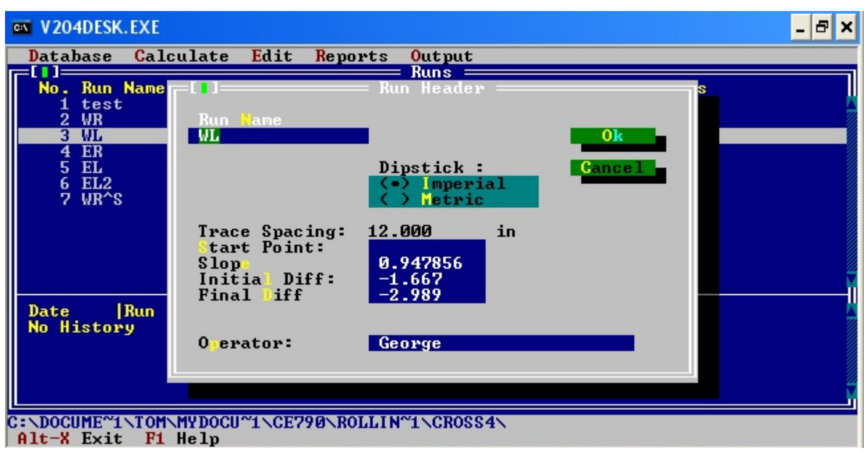

Figure 3.1.3c Set the slope equal to zero to view the original profile

Profiles collected with the Face Rolling Dipstick can be converted to .ERD files and analyzed using ProVal and RoadRuf. To do this, the elevation data must first be exported to a text file by choosing “Elevs to File” from the “Report” menu. The resulting file will contain a list of distances and the corresponding elevations as shown in Figure 3.1.3d. The first column of numbers (i.e., the distances) and the file name (in this case, WL) must then be deleted. This is most easily done by importing the text file to Excel, making the required changes, and copying the modified data back into a text file. Finally, a header must be inserted at the beginning of the modified text file. The resulting text file should be saved with an extension of .ERD. An .ERD file in the appropriate format is shown in Figure 3.1.3e. The .ERD file can then be opened in ProVal or RoadRuf.

Figure 3.1.3d Text file containing profile elevation data

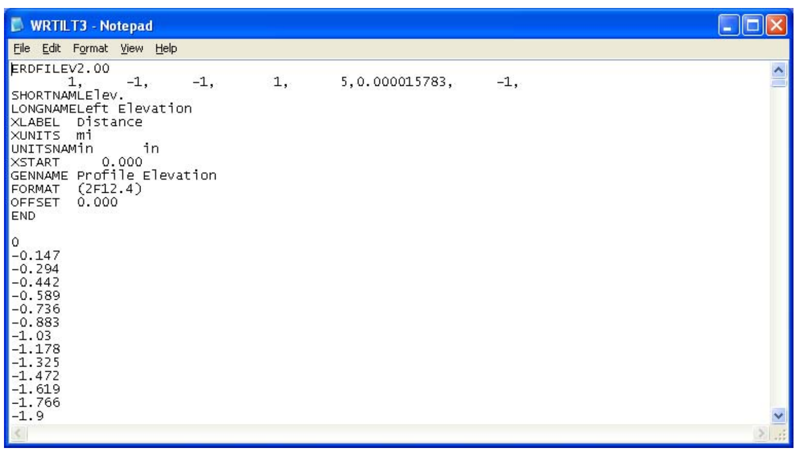

Figure 3.1.3e Text file converted to .ERD file

Profiles of several of the crossings were measured using the Rolling Dipstick. It is difficult to make a visual comparison between the profiles obtained with the Rolling Dipstick and those obtained with the Transportation Cabinet's inertial profiler because of the different scales. However, examination of the profiles obtained with the Rolling Dipstick does not reveal the distinct elevation drops corresponding to the flange ways and other cracks in the crossing surface. This was expected because of the different way in which the Rolling Dipstick measures in the profile. Note that no errors were evident in the profiles collected at the Yarnallton Road crossing, as was the case with the Transportation Cabinet's inertial profiler.

3.1.4 Roughometer II

The last device that was used to collect crossing data was the Roughometer II (Figure 3.1.4). Data were collected for crossings 1 through 9. The data were initially accessed through the Roughometer II software. An interval of 0.0066 mile, or approximately 35 feet, was specified as the distance for computing and printing the IRI values for each directional crossing. The resulting tables of results were then opened in Excel and a plot of IRI versus distance was generated for each directional crossing. For some of the crossings, an "Event" point was set as the vehicle traveled over the crossing. If available, the crossing location is noted on the plots. Where the crossing location is not noted, it can normally be identified as occurring where the IRI value reaches a global maximum.

Note that these plots do not represent continuous values of IRI: Values of IRI are only calculated at the interval specified by the user. It is therefore likely that there exists a 0.0066 mile interval on each road segment where the IRI value is higher than the maximum value shown in the plot. Also, in its current state, the software does not allow the user to work with the raw data. Therefore, custom indexes cannot be calculated for data obtained from this device.

Figure 3.1.4 A vehicle measuring IRI with the Roughometer II (left) and the Roughometer II controller (right)

3.2 DATA ANALYSIS

A regression analysis was performed on the crossings for which roughness indexes were calculated. The goal of this analysis was to examine the relationship between mean rideability rating and the various roughness indexes. Initially, the following sets of independent variables were selected: IRI; PI; and IRI and BWI. IRI and PI were both selected initially because they have been shown to correlate well rideability when applied to standard highway pavements. IRI in combination with BWI was selected because, in theory, IRI attenuates profile features occurring in the wavelengths that were used to calculate BWI. Therefore, the two indexes should provide independent information about the crossings. Bivariate plots of mean rating as a function of each of these indexes are presented in Figure 3.2a. While the data are fairly scattered, a downward trend is evident in each plot; that is, rideability tends to decrease as each of the roughness indexes increases.

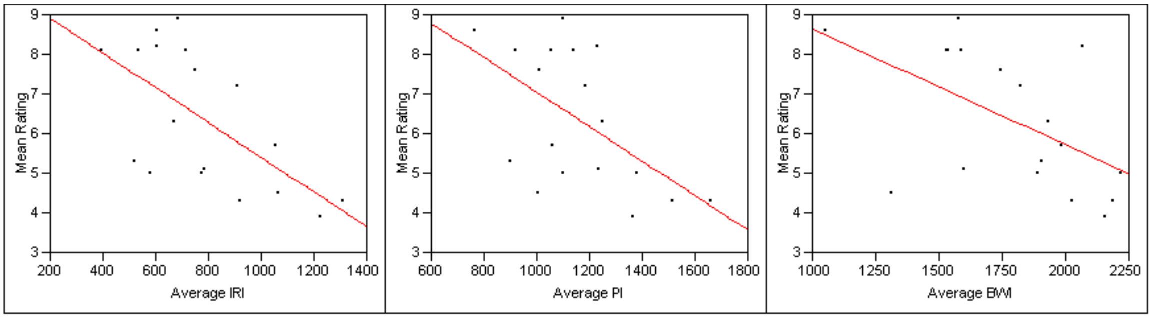

Figure 3.2a Mean rating as a function of IRI, PI, and BWI.

Several variable transformations were applied, but they did not significantly improve the fit of the data. Models using IRI, PI, and IRI in combination with BWI were applied. Two parameters were chosen to asses the goodness of fit: The coefficient of determination (R^2) and the p-value associated with the F statistic. The coefficient of determination is simply a measure of the proportion of the variation of the dependent variable (in this case, the mean rating) that has been explained by the model. The coefficient of determination can range from 0, indicating that none of the variation has been explained by the model, to 1, indicating that all of the variation has been explained by the model.

The F statistic is used to compare the residual error associated with different models. It can therefore be used to assess the significance of an overall model, as well as each of the independent variables in a multivariate model. For a given model or variable, larger values of the F statistic are indicative that the model or variable has a higher level of significance. P-values can be derived for a calculated value of the F statistic based on the F distribution. A p-value represents the probability of obtaining an F statistic greater than or equal to the calculated value if the variable or model in question actually had no effect on the dependent variable. Therefore, if a p-value of 0.05 is obtained, we would be 95% confident that the variable or model in question is significant in explaining the variation in the dependent variable.

The regression equation and its associated R^2 value for each model are presented in Table 3.2.a. The F statistic and its associated p-value are shown for each model, as well as for each variable in the bivariate model. Note that in these equations, R is the predicted mean rating.

Table 3.2a Regression analysis results for IRI, PI, and IRI & BWI models

Model	Variable	Equation	R-squared	F	p
IRI	-	R = 9.79 - 0.00439*IRI	0.405	10.9	0.0045
PI	-	R = 11.4 - 0.00435*PI	0.314	7.31	0.016
IRI & BWI	-	R = 12.6 - 0.00354*IRI - 0.00196*BWI	0.52	8.12	0.0041
	IRI	-	-	7.3	0.016
	BWI	-	-	3.57	0.078

As expected, each regression equation has an intercept of about 10. The IRI and BWI model appears to be superior to the other two models since it has the highest R^2 and p-value. Furthermore, both the IRI and BWI variables used in this model have fairly low p-values, indicating that they are highly significant. As expected, no significant cross-correlation was detected between IRI and BWI. However, the R^2 value of 0.52 indicates that only 52% of the variation in the mean rating has been explained by this model. For a model to be applied in practice, a better fit would probably be required.

In the process of examining the relationship between the various roughness indexes and rideability, it was noticed that although the concrete crossings had very high rideability ratings, their roughness indexes were not particularly low. Therefore, an indicator variable called C was created. This variable takes a value of 1 for concrete crossings and 0 for other types of crossings. Two new models were proposed: One based on IRI, BWI, and C, and the other based on IRI and C. A regression analysis was performed on each of these models. The results are presented in Table 3.2.b.

Table 3.2b Regression analysis results for IRI, BWI, & C and IRI & C models

Model	Variable	Equation	R-squared	F	p
IRI, BWI, & C	-	R = 7.07 - 0.00158*IRI - 0.00038*BWI + 2.67*C	0.917	51.3	<0.0001
	IRI	-	-	6.64	0.022
	BWI	-	-	0.596	0.45
	C	-	-	66.7	<0.0001
IRI & C	-	R = 6.41 - 0.00165*IRI + 2.77*C	0.913	78.9	<0.0001
	IRI	-	-	7.5	0.015
	C	-	-	9.37	<0.0001

From Table 3.2b, it is clear that the addition of the indicator variable C dramatically improved the R^2 values. However, the significance of BWI is now highly questionable. The p-value of 0.45 for this variable indicates that there is a 45% chance that BWI has no effect on mean rating. In addition, the R^2 value for the two-variable model is almost identical to that for the three-variable model. Therefore, the model based on IRI and C is recommended as the preferred model. Using two independent variables, this model explains over 91% of the variation in mean rating among the crossings considered in this study.

While this model explains most of the variation in rideability among the crossings considered in this study, it does have some drawbacks. The fact that the indicator variable C is highly significant may simply be due to the fact that the concrete crossings considered in this study were in very good condition. If some rougher concrete crossings had been included in the study, the indicator variable may not have been as significant. Even if this issue could be resolved, new indicator variables would have to be introduced for crossings constructed of a material other than concrete or asphalt. It would therefore be desirable to develop a model that explains a large amount of the variation in rideability without using the crossing type as an independent variable.

One potential reason for the low correlation between the roughness indexes and rideability may be the fact that the Transportation Cabinet's inertial profiler will record the elevations of points at the bottom of narrow cracks in the crossing surface, such as the flange ways, that are not actually felt by a vehicle traveling over the surface. While such points are irrelevant to ride quality, they can affect the roughness indexes. To illustrate this point, the wheel-path profiles obtained with the Face Rolling Dipstick and those obtained with the Transportation Cabinet's inertial profiler at the eastbound Waller Avenue crossing are presented in Figure 3.2a. A photograph of this crossing is presented in Figure 3.2b. Clearly, the geometry of the Rolling Dipstick has caused it to filter out some of the irrelevant points. Otherwise, the general shapes of the profiles measured with the two devices are very similar.

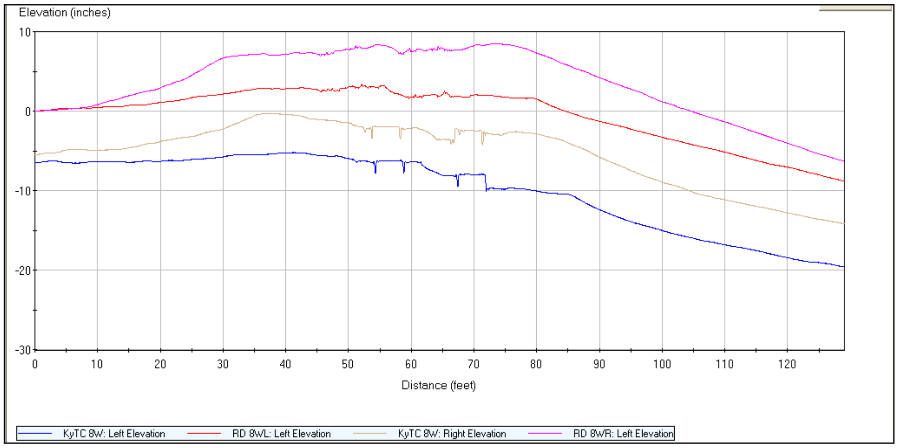

Figure 3.2a Profiles obtained with the Rolling Dipstick (top) and with the KYTC inertial profiler (bottom) for the Waller Avenue crossing

Figure 3.2b Photograph of the Waller Avenue crossing

A preliminary review of the data obtained with the Rolling Dipstick indicates that the IRI values are quite similar to those obtained with the Transportation Cabinet's inertial profiler. Based on this preliminary analysis, it appears that IRI is responding primarily to the high-wavelength roughness that occurs when crossings are located on a noticeable hump in the road. The Yarnallton Road crossing, for example, had an IRI value on the order of 2,000 inches per mile, which is extremely high. The IRI values obtained with the Roughometer II appear to follow a similar pattern.

3.3 FINDINGS

In this study, three different methods were used to obtain roughness-related data at a number of different crossings: The Transportation Cabinet's inertial profiler, the Face Rolling Dipstick, and the Roughometer II. The first two devices measure surface profiles, from which various roughness statistics can be calculated. The third device measures the deflection of the left side of the rear axle of a passenger car, along with speed and distance, as the car travels over a surface. A black-box approach is then used to compute IRI values from this data.

The Transportation Cabinet's inertial profiler is capable of obtaining fairly accurate profile measurements very quickly. The amount of time and labor required to obtain measurements is small, and there is little, if any, disruption to the flow of traffic. The data files obtained using these methods are directly compatible with the popular profile analysis software packages. This method has two disadvantages: First, points which are irrelevant to ride quality but that may affect roughness indexes are included in the analysis, which may result in poor correlation with rideability. It may be possible to mask these points using a computer algorithm. Second, erroneous results may be obtained for very rough crossings.

The Rolling Dipstick appears to be capable of obtaining good results even on very rough crossings. The IRI values obtained with this device appear to compare favorably with those obtained from the Transportation Cabinet's inertial profiler. While this device is much faster to use than some of the other methods considered, it is still much slower than the inertial profiler. In most cases, a crossing must be closed for several minutes while measurements are taken, which is disruptive to traffic. Also, there are apparently some bugs that need to be worked out with the computer that is used with this device.

The Roughometer II does not measure actual surface profiles. Instead, it measures the displacement of a point on the axle of a passenger car as the car travels over the surface of interest. Vehicle speed and distance traveled are also measured by the device, and a computer program uses this information to compute IRI. The computer program does not display the raw data, making it impossible to perform custom analyses. Because IRI has been shown to explain only a moderate proportion of the variation in crossing rideability, the utility of this system in its current state is limited. However, this system could potentially be modified to provide an acceptable alternative to measuring the wheel-path profiles directly.

Several roughness indexes were computed from the wheel-path profiles that were measured using the Transportation Cabinet's inertial profiler. A regression analysis was performed to determine the relationship of these indexes to the subjective rideability ratings of the crossings. It was found that approximately 50% of the variation in crossing rideability could be explained by using IRI in combination with BWI, where BWI is calculated after applying a filter that attenuates profile features occurring at wavelengths above 4 feet and below 1 foot. Over 90% of the variation in crossing rideability could be explained by taking into consideration the type of crossing (i.e. concrete or asphalt), but it would be preferable to develop a relationship that does not depend explicitly on the type of crossing.

The International Roughness Index appears to explain the effect of roughness occurring at high wavelengths, but it does not seem to respond to roughness occurring at shorter wavelengths, which is typical of crossing surface deterioration. For future research, it is suggested that effort be applied to the development of a roughness index that respond to this type of roughness in a way that correlates well with rideability. It has been hypothesized that the inclusion of points that are irrelevant to ride quality, such as those in the flange ways and other small cracks or voids in the crossing surface, may have an adverse effect on this correlation. This hypothesis could be tested by applying various analysis procedures to the profiles measured with the Transportation Cabinet's inertial profiler and those measured with the Rolling Dipstick simultaneously. If significantly improved correlation was obtained using the profiles measured with the Rolling Dipstick, it could be concluded that the irrelevant points are indeed having an adverse effect. In addition, the Roughometer II could potentially be modified and used as an alternative method to quantify rideability.

Once an appropriate method to quantify rideability is developed, criteria could be established to prioritize crossings for improvements. These criteria would probably include the importance of the route and the amount of traffic using it in addition to the roughness of the crossing. In addition, the relationship between crossing roughness and safety could be examined, as it has been hypothesized that rough crossings may have a negative impact on safety (Adwell, 2004). Finally, the roughness indexes could be used as a criterion for evaluating the long-term performance of various crossing installations.

CHAPTER 4. PHASE TWO: FOLLOW-UP TESTING OF RAILROAD-HIGHWAY AT-GRADE CROSSINGS

4.1 RESEARCH METHODOLOGY

The study group for this project consisted of 26 railroad-highway at-grade crossings along Norfolk Southern Railway, CSX Transportation and RJ Corman Railroad Company lines in the greater Fayette County, Kentucky area. Each crossing is a public crossing with two-way traffic, meaning there are two wheel-paths at every crossing; for this reason each direction of every crossing was handled as an individual crossing. One crossing in the test had more than one lane in either direction, at this crossing only the outside highway lanes were analyzed. In order to create a short-hand for the project, each crossing was assigned a number and direction. For example, the Forbes Road crossing adjacent to the Pepsi Plant is designated crossing number 1, with a direction of north or south. A complete list of the crossings studied in this project is included in Table 4.1.

4.1.1 Objective Ratings

Objective ratings of the individual crossings were obtained by individuals participating at the University of Kentucky and members of the KYTC Railroad Committee. The developed ratings were to represent the rideability or ride quality of each crossing from the perspective of a vehicle operator. The participants were given a map of the crossings and were told to rate the crossings on a scale of 1 to 10, with 1 being the worst and 10 being the best. The individuals were told that ratings of 1-3 would represent crossings in need of immediate repair. A rating of 4-7 represented an adequate crossing lacking in quality and an 8-10 rating designated a very acceptable railroad-highway at-grade crossing. Participants were told to traverse the crossings in both directions with their vehicle at a speed of 25-30 mph and then score the crossing objectively using the previously discussed scale. The individual objective ratings for each crossing are represented in Table 4.1.1. This table is ordered from lowest to highest individual mean ratings. The variance between individuals is displayed graphically in Figure 4.1.1a. Each individual point is a rating and the line represents the mean rating of each crossing. There is a great deal of variation in the objective ratings for each individual, for that reason, the objective ratings were normalized. The normalized objective ratings are displayed in Figure 4.1.1b.

In addition to giving the crossing a number rating, the contributors were asked to comment on whether the roughness was a result of the crossing surface, pavement approach or the vertical profile of the crossing (hump or sag). The first type of roughness regarding the crossing surface occurs from differential settlement, deterioration of the crossing surface, or improper installation of the crossing surface. This roughness occurs at 20 feet on either side of the crossing.

Roughness due to pavement approaches is characterized by a rough transition from the highway pavement to the pavement wedge for the railroad crossing. This distance varies with each crossing; some crossings have no approaches where others have approaches greater than 100 feet in length. A detailed crossing survey is needed to determine the length of highway approaches for each individual crossing.

Table 4.1 Phase Two Crossing Listing

Crossing Number	Crossing Location	Highway Direction	Crossing Type	Number of Tracks
1	Forbes Rd (Pepsi)	N/S	Concrete	1
2	Forbes Rd (Stockyards)	N/S	Concrete	1
3	Alexandria Drive (New Circle)	E/W	Rubber Seal and Asphalt	1
4	Alexandria Drive	N/S	Rubber Seal and Asphalt	1
5	Yarnallton	N/S	Rubber Seal and Asphalt	1
6	Paynes Depot	N/S	Rubber Seal and Asphalt	1
7	Main Street (Midway)	N/S	Rubber Seal and Asphalt	1
8	Pisgah Pike	N/S	Timber and Asphalt	1
9	Versailles Rd	E/W	Concrete	1
10	Clifton Rd	E/W	Rubber Seal and Asphalt	1
11	Spurr Rd	E/W	Rubber Seal and Asphalt	1
12	Greendale Rd	N/S	Rubber Seal and Asphalt	1
13	Waller	E/W	Concrete	2
14	Rosemont Garden	E/W	Concrete	2
15	Brannon Rd	E/W	Rubber Seal and Asphalt	1
16	Louden Ave	E/W	Rubber	1
17	Russell Cave Rd	N/S	Rubber Seal and Asphalt	1
18	Bryan Station Rd	E/W	Timber and Asphalt	1
19	Briar Hill Rd	E/W	Timber and Asphalt	1
20	Main Street (Winchester)	N/S	Concrete	2
21	Broadway, Winchester	E/W	Rubber Seal and Asphalt/Concrete	2
22	Flanagan/Bybee	N/S	Rubber Seal and Asphalt/Concrete	2
23	KY 328	N/S	Rubber Seal and Asphalt	1
24	Irvine St (Richmond)	E/W	Rubber Seal and Asphalt	2
25	Main St (Richmond)	N/S	Concrete	1
26	Boggs Lane (Richmond)	N/S	Rubber Seal and Asphalt	2

Table 4.1.1 Objective Rating Tables and Figures

Table 4.1.1-Objective Rating Table

Crossing Information		**Ratings**											
Crossing #	Location	Vint	Witt	Mitchell	Hullinger	Ball	Renfro	Farmer	Lewis				Mean
5	Yarnallton	2	3	6	5	4	3	4	6				4.13
7	Main St, Midway	3	4	3	4	4	3	5	7				4.13
23	KY 388	3	5	3	3	3	3	6	7				4.13
6	Paynes Depot	4	5	5	5	4	4	4	6				4.63
3	Alexandria Dr (New Circle)	3	6.5	3	3	5	4	6	7				4.69
16	Louden Ave	4	7	5	5	5	5	6	6				5.38
8	Pisgah	4	4.5	8	7	3	4	6	8				5.56
10	Clifton Rd	6	5.5	4	5	5	5	7	7				5.56
4	Alexandria Dr	5	7	3	3	7	5	7	8				5.63
24	Irvine St, Richmond	5	4.5	6	7	6	6	5	6				5.69
17	Russell Cave	4	6.5	6	6	6	6	6	8				6.06
26	Boggs Lane, Richmond	6	5.5	5	5	8	6	6	7				6.06
12	Greendale Rd	7	7	4	4	5	7	6	9				6.13
19	Briar Hill	6	6	6	6	5	6	7	7				6.13
1	Forbes (Pepsi)	6	9	4	3	7	6	7	9				6.38
2	Forbes (Stockyard)	6	8.5	4	4	6	6	8	9				6.44
22	Flanagan/Bybee	5	7.5	8	7	5	6	6	7				6.44
15	Brannon	5	6	7	6	6	6	7	9				6.50
18	Bryan Station	6	7	6	7	7	6	7	8				6.75
11	Spurr Rd	6	8	6	7	7	8	6	9				7.13
21	Broadway, Winchester	7	8.5	8	6	8	7	8	8				7.56
20	Main St, Winchester	8	8.5	8	8	8	8	8	9				8.19
14	Rosemont	8	7.5	8	8	8	7	9.5	10				8.25
13	Waller Ave	8	9	6	8	9	8	9.5	10				8.44
25	Main St, Richmond	9	9	9	9	7	8	9.5	9				8.69
9	Versailles Bypass	9	9.5	8	8	8	9	9.5	10				8.88

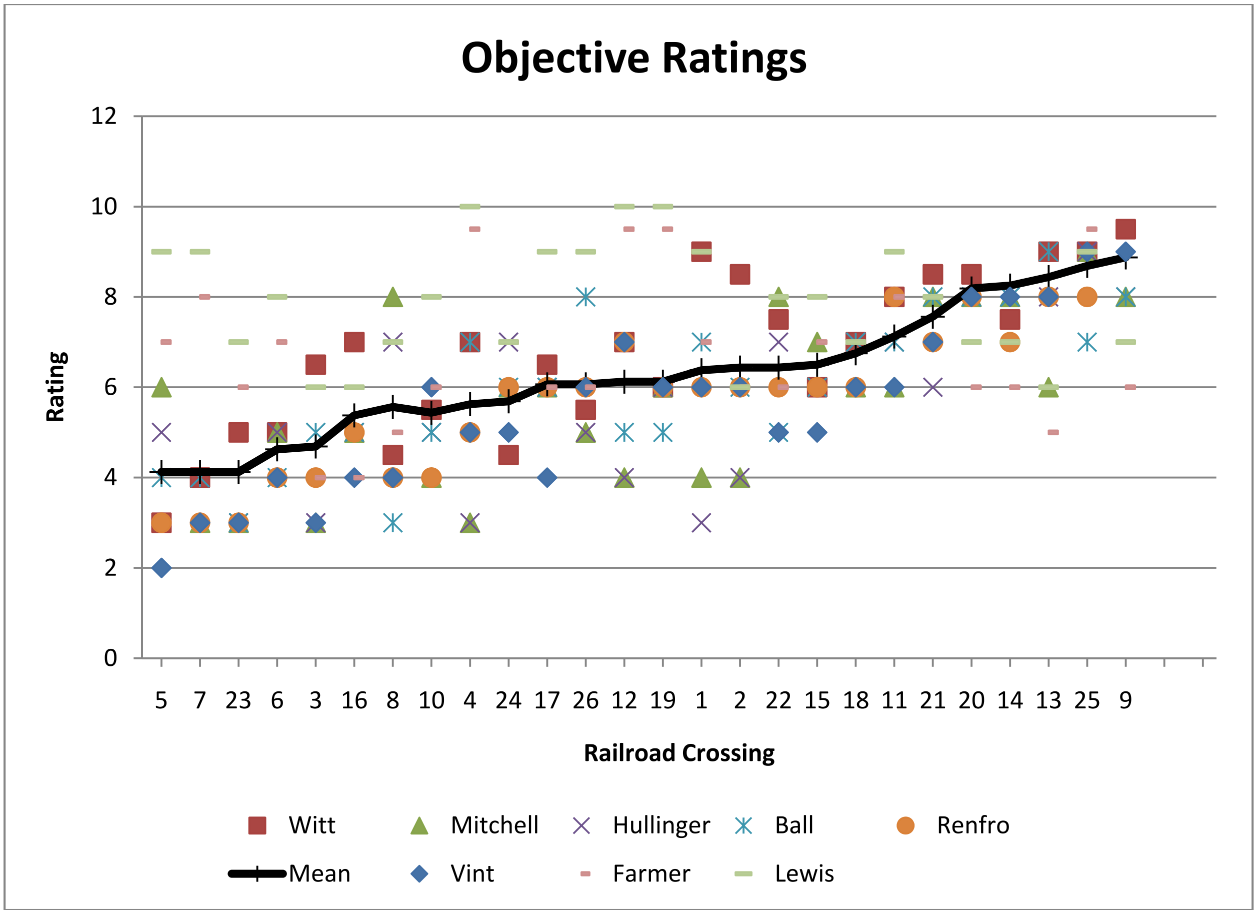

Figure 4.1.1a Graphical Display of Objective Ratings

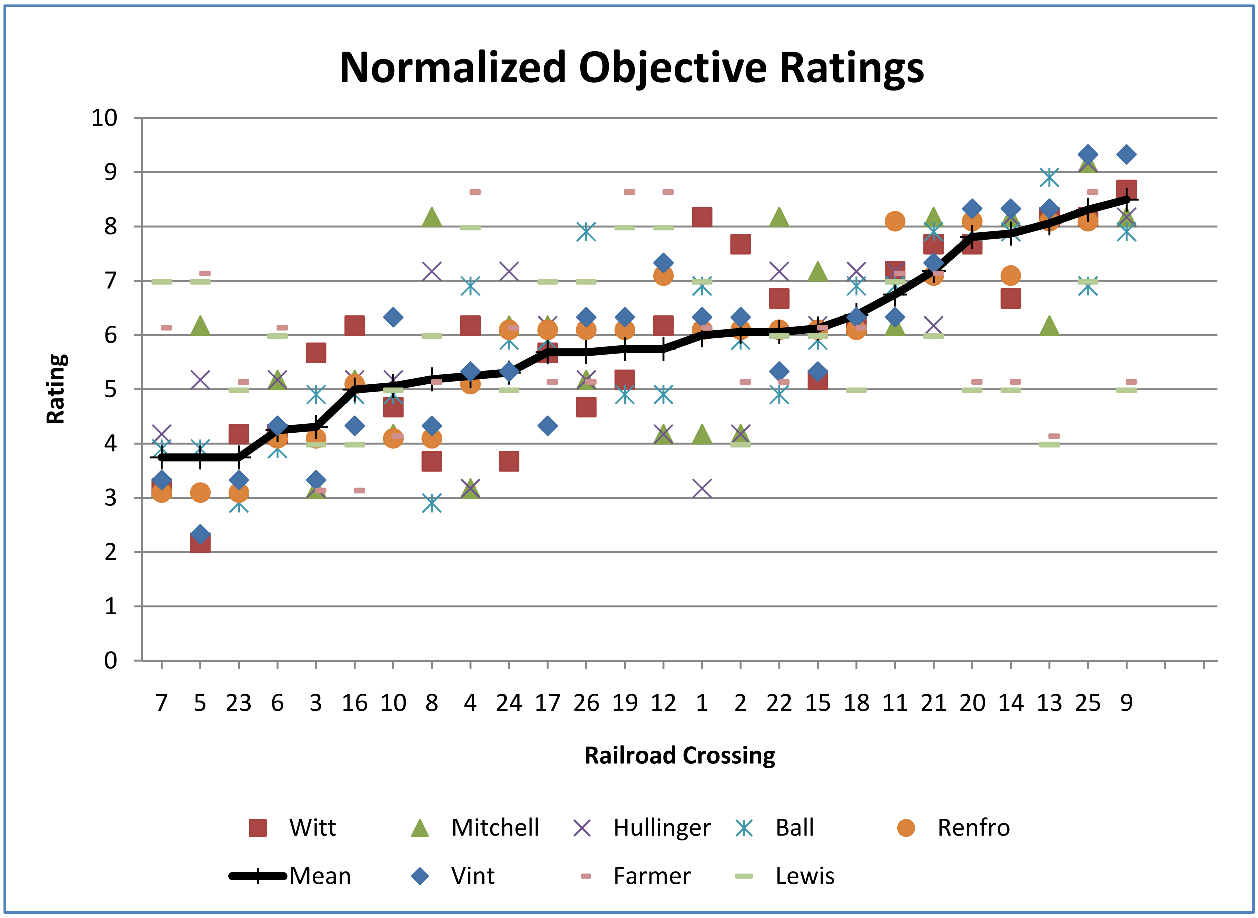

Figure 4.1.1b Graphical Display of Normalized Objective Ratings

Roughness due to the vertical profile of the railroad-highway crossing is most noticeable with crossings that have a significant hump. This carries a great deal of fault for crossings that scored low on rideability objective ratings. The vertical profile causes roughness most notably in the 50-75 feet forward of the crossing centerline and an additional 50-75 feet past the crossing. Since this measurement is predictable over the greater distance, it is used to determine the roughness of the crossings in this study.

Ideally, the data could be separated and analyzed into roughness due to each of the individual sources of railroad-highway crossing roughness. Knowledge of the different railroad components would be advantageous in order to determine the type of mitigation necessary to improve the crossing; if the crossing is rough due to the surface, the surface could be reconstructed. If the approaches are at fault, the approaches could be improved. Using this information, a cost effective solution for improving the crossing is more easily obtained.

4.1.2 Crossing Surveys

The next portion of the project was to create a crossing inventory of the different characteristics of each crossing. The information included in the inventory was: crossing surface type, crossing surface condition, geometry of the crossing, width of crossing surface(s), approach length, approach condition, general comments and an effective width estimation. The geometry of the crossing involves the angle at which the railroad crossing intersects the highway or skew. In addition to the skew, the geometry characteristic makes note of the vertical profile of the crossing: humped or sagged. This information will aid in data analysis by being able to separate crossings that are perpendicular to the highway from the ones that intersect it at an angle. The geometry may play an important role in the measured roughness of the crossing.

The effective width estimate portion of the crossing inventory is an estimate regarding the length of the railroad crossing that contributes to roughness. The effective width is essentially the sum of the crossing surface width and the length of both approaches. When analyzing the roughness associated with individual railroad crossings, it would be desirable to match the effective width estimate with the generated roughness plot from the analysis. Ideally, these two measures should be equal to one another, that is, the effective width of the crossing should equal the width of the IRI plot. Crossing surveys for each individual crossing can be found in (Renfro, 2008 Appendix C).

4.1.3 Crossing Wheelpath Profiles

In order to acquire wheelpath profiles of the selected railroad crossings in this project two different highway profilers were utilized. Both the KYTC Profiler (Figure 4.1.3a) and the NCAT ARAN Profiler (Figure 4.1.3b) profiled each crossing in both directions. The procedures for both inertial profilers are outlined previously in this report. To ensure accuracy it was essential that the profilers traveled in the precise wheelpath of the highway and railroad crossing. Figure 4.1.3c, shows a schematic of how the railroad-highway crossings were measured.

Figure 4.1.3a Kentucky Transportation Cabinet's Inertial Profiler

Figure 4.1.3b National Center for Asphalt Technology's Automated Roadway Analyzer

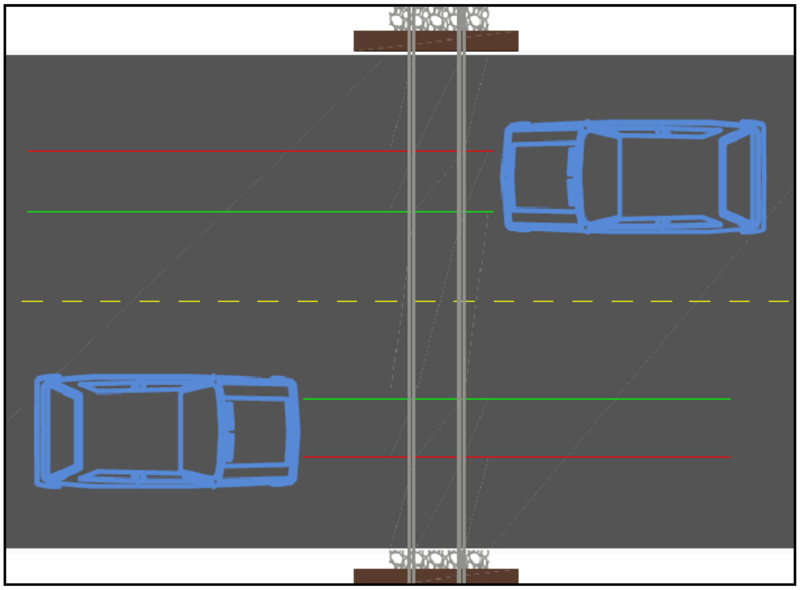

Figure 4.1.3c Crossing Profile Measurement

From Figure 4.1.3c, the green line represents the left wheelpath measured by the left laser and the red line represents the right wheelpath measured by the right laser of the profilers. The KYTC profiler stored the profile data in an .ERD file that could be analyzed further using a generic profiling software. This file type can be used to create both profile and IRI roughness plots (for analysis the MRI was used). The ARAN vehicle did not create this file type that could be used to plot the raw profiles of the crossings in the study. The ARAN vehicle did provide a report of the IRI statistic calculated at every 25 feet; which could be used to plot the IRI statistic.

The software package used to analyze the .ERD files produced by the KYTC Profiler was ProVal, version 2.7. ProVal produced wheelpath profile plots and MRI plots for each test pass over the selected railroad crossings in this project. A sample profile and MRI plot are included below on the following page as Figures 4.1.3d and 4.1.3e.

Figure 4.1.4 graphs the deviation from a level surface in inches in respect to the longitudinal distance travelled in feet. The sharp vertical lines represent each rail in the railroad crossing. The MRI plot shows the calculated MRI value, obtained from the average of the IRI values of each wheelpath, with respect to the longitudinal distance travelled. As expected, the roughness statistic grows significantly after 100 feet, which was the beginning of the crossing. The residuals of this roughness carry out nearly another 100 feet passed the crossing. The completed ProVal reports for each crossing are located in (Renfro, 2008 Appendix D).

The data produced by the ARAN vehicle was not compatible with ProVal software, but the MRI reports were sufficient to create plots using Microsoft Excel displaying the roughness as a function of longitudinal distance. Figure 4.1.3f displays the plot from the NCAT ARAN data. Similarl to the plots produced from the KYTC profiles using ProVal, the ARAN plots also show the change in the roughness variable, MRI, with respect to longitudinal distance travelled. The completed plots for all crossings are included in (Renfro, 2008 Appendix E).

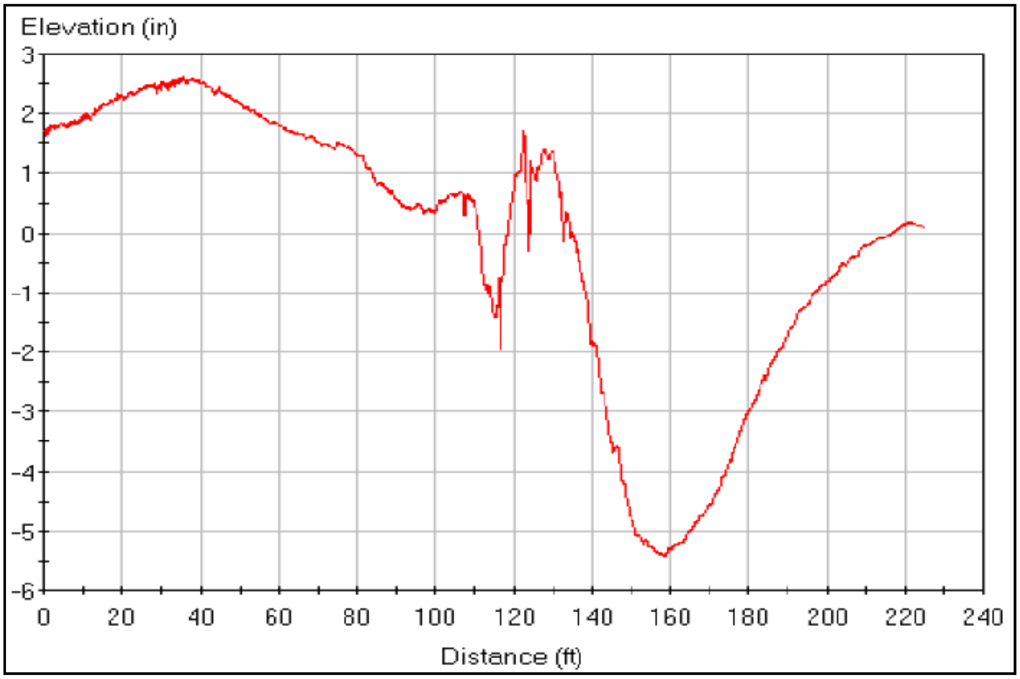

Figure 4.1.3d ProVal Example Profile Plot

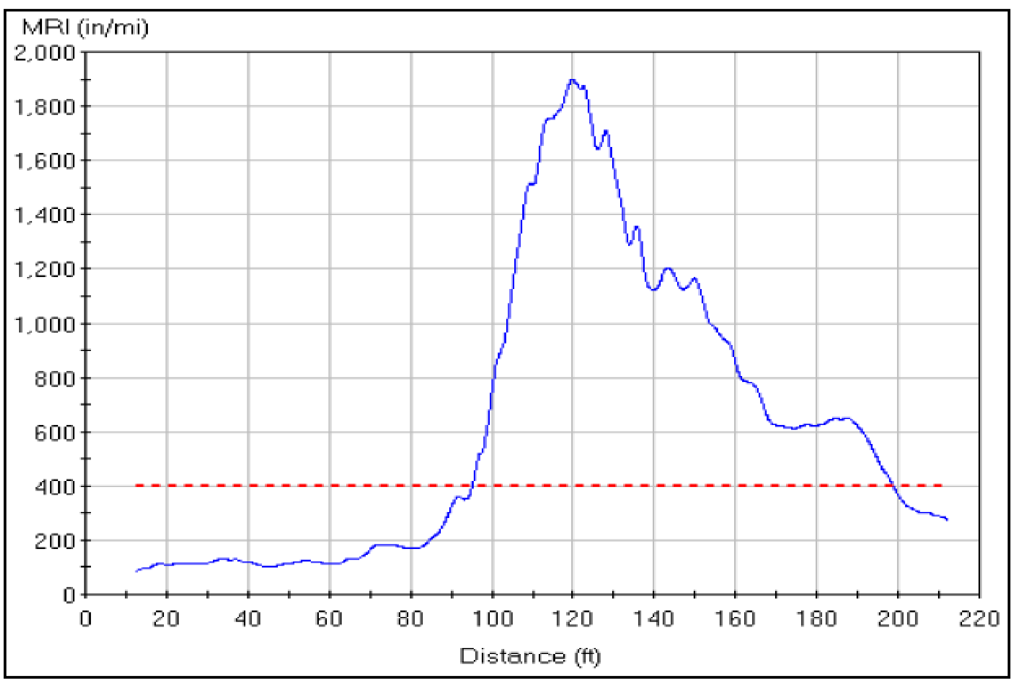

Figure 4.1.3e ProVal Example MRI Plot

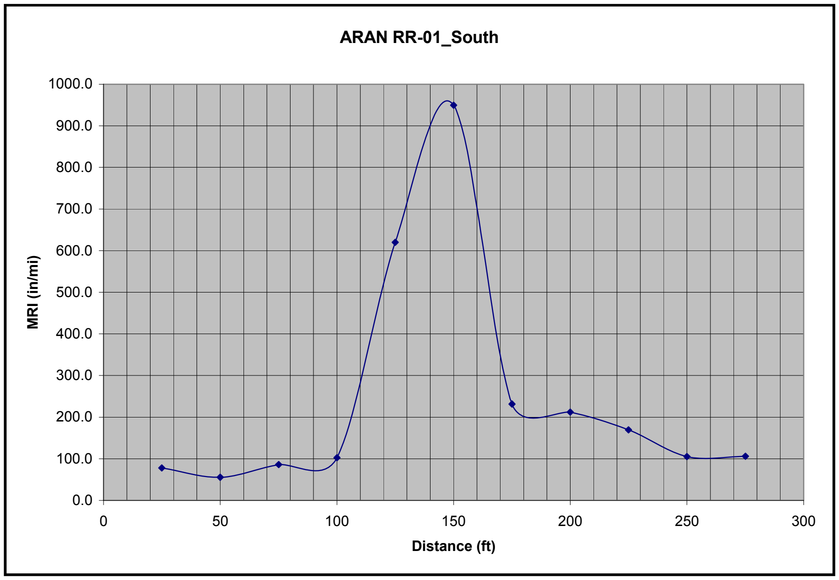

Figure 4.1.3f - ARAN MRI Example Plot

4.2 DATA ANALYSIS

Upon examination the IRI plots of various crossings exhibited one of two general forms; a sharp vertical spike in roughness in the region immediately before and after the crossing or a long width of roughness that stretched well before the beginning of the crossing and well after the crossing. An example of each type of graph is included below as Figures 4.2a and 4.2b. Figure 4.2a shows the roughness associated with this crossing occurring 15 feet prior to and after the crossing, conversely, the roughness plot in Figure 4.2b shows that the roughness is nearly 50 feet before and after the crossing. As a result of these characteristics associated with the MRI plots, it was determined that the data should be analyzed based both on the peak roughness value and the "area" of the roughness.

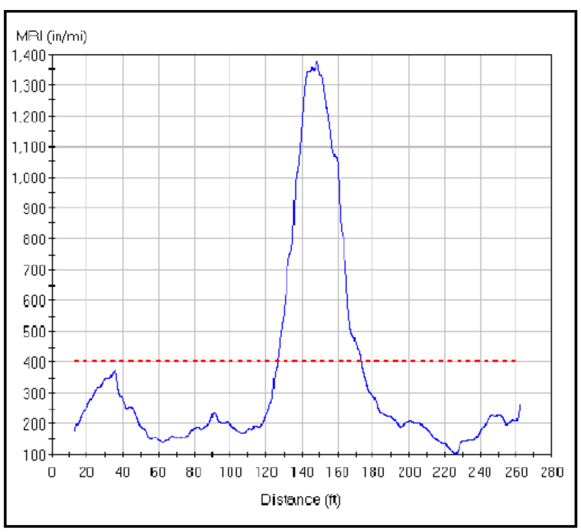

Figure 4.2a Narrow MRI Plot

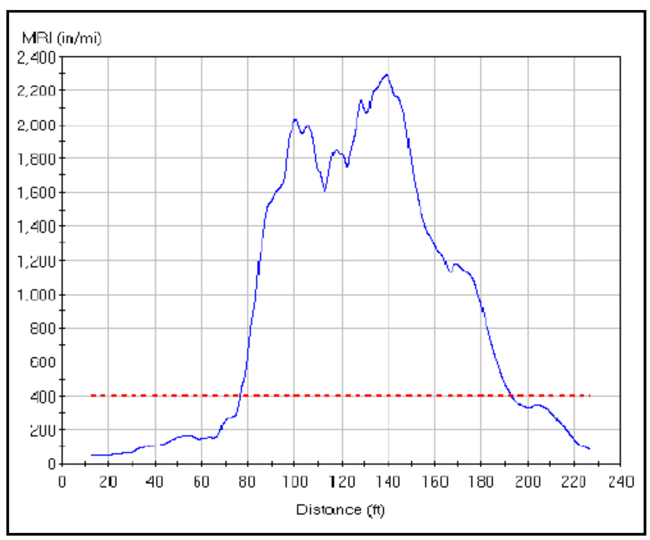

Figure 4.2b Wide MRI Plot

The peak roughness value is obtained from reading the data files associated with each railroad crossing. The “area” calculation established by determining the distance of the roughness caused by the railroad-highway crossing. This distance was where roughness associated with the crossing began and where it ended. After analyzing the completed MRI plots and referencing Figure 1.5, it was determined that an MRI value of 400 in/mi was the beginning of the roughness associated with the crossing. According to Figure 1.5, the roughest roads based on IRI values do not measure more than around 350 in/mi, which correlated well with the project data. Using this conclusion, the distance of roughness started at the point where a MRI plot reached 400 in/mi and ended where the plot fell below 400 in/mi.

ProVal allows the user to set a baseline for defective segments at an arbitrary roughness value, the dashed red line on Figures 4.2a and 4.2b marks this 400 in/mi MRI defective value. The generated reports give the defective segment start and end points, easily facilitating a distance calculation. Unfortunately, ProVal is not capable of calculating the areas under the curves it generates, so each plot was assumed to be triangular to facilitate area calculation. Under this assumption the equation for the area of a triangle (0.5*base*height=area) was used. In this case, the height is the peak MRI value minus 400 and the base is the distance given from ProVal as the “defective segment.” The MRI plots obtained from the ARAN vehicle were produced in Excel and the area under those plots was estimated by counting the scaling the area under the MRI curve. A summary of these values for all of the crossings in the project is included in Table 4.2a.

Table 4.2a MRI Values

Crossing #	KYTC Avg Area ([in/mi]*ft)	KYTC Avg MRI (in/mi)	ARAN Avg Area ([in/mi]*ft)	ARAN Avg MRI (in/mi)
1	24,470	1028	24,000	1243
2	40,515	1139	49,000	1563
3	82,587	1711	88,000	2111
4	82,508	1926	76,000	1995
5	208,130	3202	307,500	6236
6	143,177	2859	181,500	3984
7	165,743	2469	196,000	4126
8	53,880	1557	52,000	1514
9	20,542	966	13,000	832
10	18,003	654	18,000	1035
11	39,834	1042	40,000	1191
12	125,013	2038	160,000	3337
13	38,036	945	33,000	1182
14	56,528	1288	66,000	1246
15	48,545	1008	58,500	1573
16	76,665	1977	47,500	1635
17	63,526	1588	37,500	1298
18	41,680	1188	28,500	1184
19	83,764	1734	113,000	2685
20	77,475	1608	96,000	2415
21	95,413	1527	92,000	1735
22	109,061	1907	128,000	2207
23	269,221	4142	306,000	5605
24	211,630	2792	196,000	3126
25	29,353	923	24,500	1040
26	123,108	1930	161,000	2507

A regression analysis was performed for each of the roughness values associated with the railroad-highway crossings in this study. This analysis was aimed to examine the correlation between the roughness values associated with each crossing and the objective rating assigned to the crossing. The independent variables selected for this analysis were MRI peak values and MRI Areas obtained from both vehicles. The plots associated with these regression analyses are included below as Figure 4.2c. The linear regression shows the general tendency of roughness to increase as the objective rating decreases. Unfortunately, the data points have great variation, which is evident in the calculated R^2 values from the regression analysis.

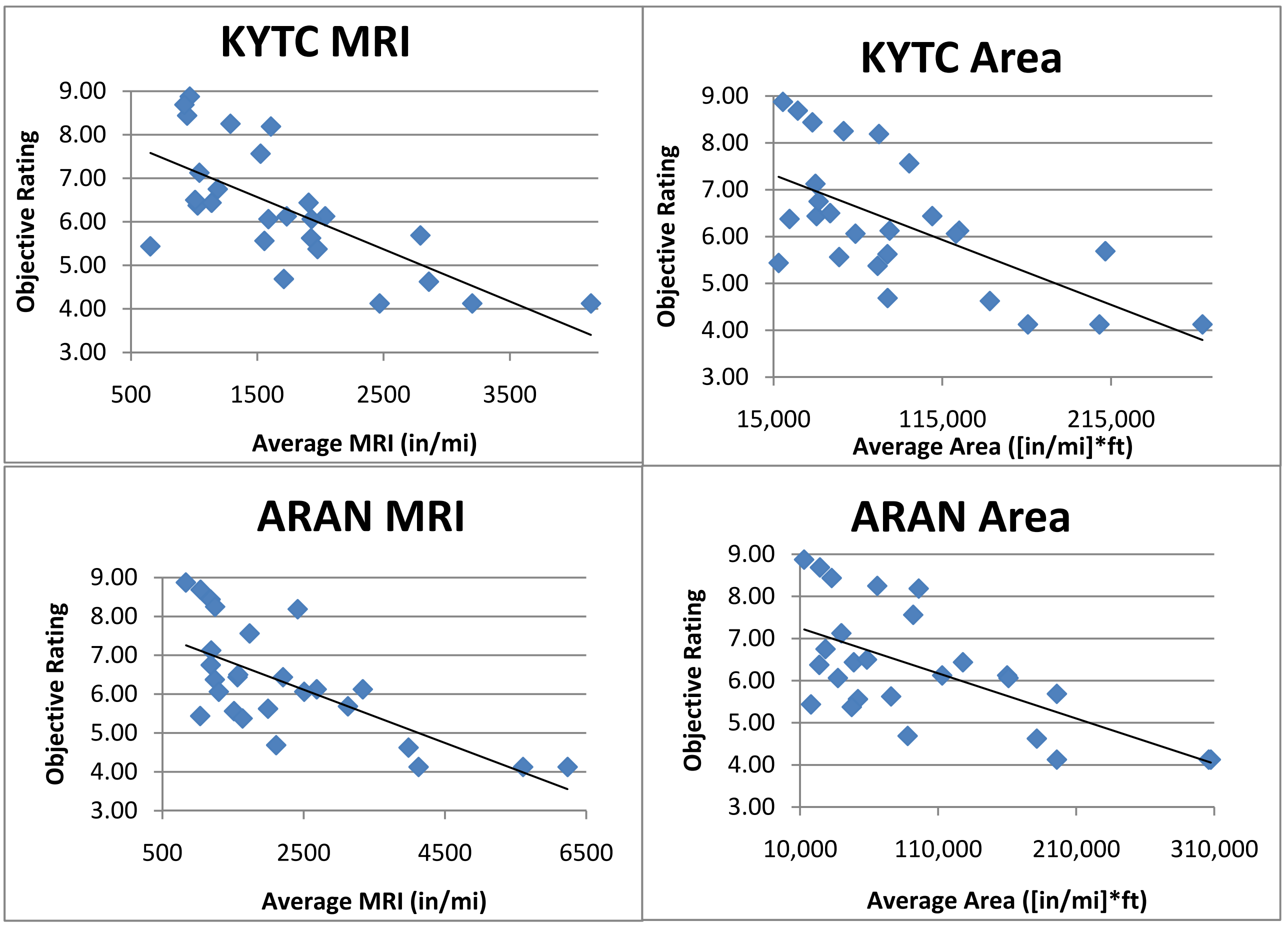

Figure 4.2c Regression Analysis Plots

The equations and R^2 values for each of the analyses are included below in Table 4.2b.

Table 4.2b Regression Analysis Results

Variable	Equation	R^2 Value
KYTC MRI	y = -0.00119(MRI)+8.363	0.48
KYTC Area	y =-1*10^{-5}(Area)+7.524	0.41
ARAN MRI	y = -0.00065(MRI)+7.827	0.47
ARAN Area	y = -1*10^{-5}(Area)+7.353	0.40

Upon review of the regression analyses, it became evident that the data seemed to fit an exponential regression more so than the linear regression that was initially used. Also, the normalized objective ratings may be more appropriate for performing the analysis. For these reasons, the data was examined again utilizing an exponential regression and the normalized objective ratings, the results are included below as Figure 4.2d.

The equations and R^2 values for each of the analyses are included in Table 4.2c.

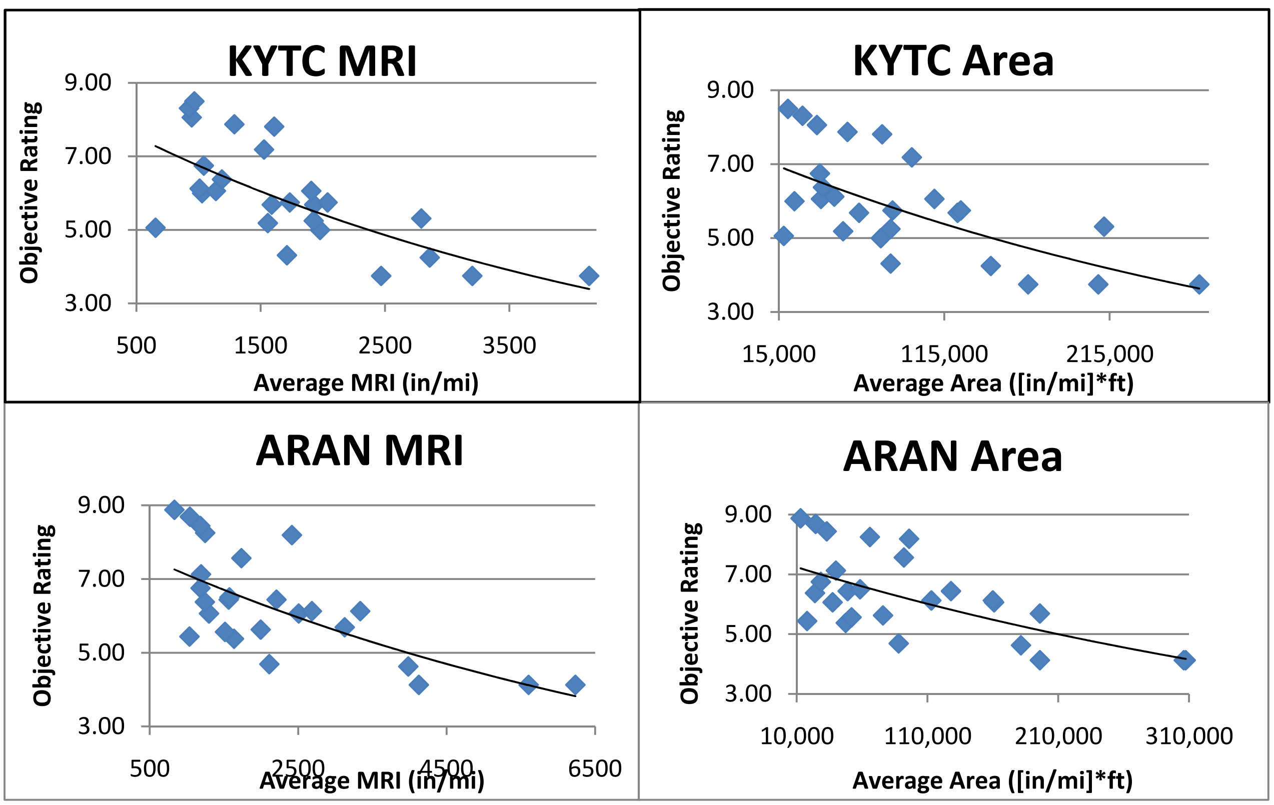

Figure 4.2d Exponential Regression Analysis

Table 4.2c Exponential Regression Results

Variable	Equation	R^2 Value
KYTC MRI	$y = 8.397352e^{-0.000219x}$	0.539
KYTC Area	$y = 7.209e^{-3E-0x}$	0.461
ARAN MRI	$y = 8.013493e^{-0.000119x}$	0.537
ARAN Area	$y = 7.375e^{-2E-0x}$	0.458

The R^2, or coefficient of determination, is a measure of the correlation of the regression model with the data; a perfect correlation would obtain a R^2 value of 1, a set of data with no correlation at all would have a value of 0. The number associated with the coefficient of determination is a measure of the variation of the dependent variable (Mean Rating) explained by the model. The model with the least variance is the KYTC Peak MRI, but the R^2 value is only 0.539, meaning that this model only explains 53.9% of the variation in the mean objective rating. In order to adopt this measure as a standard model a better correlation would be required.

There are several things that can help to explain the variability between roughness and rideability of these measurements, the first being laser profilers pick up features on the highway surface that do not directly effect rideability. One such feature is the flangeway in railroad crossings, flangeways are not felt by the driver when traversing the crossing, but this feature does contribute to the roughness associated with the crossing. Other features of this type include the voids in rubber crossings and depressions in concrete crossing panels used for placement.

Another factor is that the profilers and associated roughness indexes used in this study were designed and developed to measure highway pavements generally no shorter than a quarter mile long. The testing in this project was performed at the lower limit of each vehicle capability, 200 feet for the KYTC Profiler and 400 feet for the ARAN vehicle. The IRI calculations based on both measurements is a moving 25 foot average, meaning the minimum accurate reading for roughness is 25 feet. Rarely is a railroad-highway crossing 25 feet wide, thus the roughness associated with the crossing surface alone is stretched throughout the analysis area.

A third factor that can help explain this variability in the correlation between rideability and roughness is the IRI statistic in general. When IRI was developed it included three vehicle response measures: road meter response, vertical passenger acceleration and tire load. It became evident through the data analysis that a level crossing with a very poor crossing surface has a much lower IRI value than a crossing in a sag or even more so in a crest curve, regardless of the crossing surface condition. This factor is particularly evident when comparing the crossings at Clifton Road with Brannon Road. The crossing surface at Clifton Road is in subpar condition, the rideability rating is 5.44, the MRI value is 654 in/mi (KYTC) and the crossing is level. The crossing at Brannon Road is recently rehabilitated and the surface is in excellent condition, rideability rating is 6.5, the MRI value is 1008 (KYTC) and the crossing has humped vertical profile. Clifton Road ranks as either the 1^{st} or 2^{nd} smoothest crossing in the study based on roughness, but is 22^{nd} in rideability. Conversely, Brannon Road is 11^{th} in rideability and ranks either 11^{th} or 14^{th} by roughness. This variation in roughness measurement shows that a level crossing tends to be measured much smoother than a crossing with a change in vertical elevation. It would seem that a roughness statistic that considered the vertical axle acceleration of a vehicle would account for the roughness associated with deteriorated crossing surfaces as well as the vertical profile of the railroad crossing.

4.3 FINDINGS

This project utilized two different laser-based highway inertial profilers to obtain wheelpath profiles of 26 railroad-highway at-grade crossings in the greater Fayette County, Kentucky area. The wheel path profiles obtained from each profiler were used to calculate roughness statistics for the crossings included in the study. The calculated roughness statistics for each crossing were then compared to objective rideability ratings obtained during the study.

Both the Kentucky Transportation Cabinet and ARAN vehicles were able to obtain wheelpath profiles of the crossings in the study quickly and with little difficulty. The crossings in the study were all measured within a total time of about three days, other methods would have taken much longer to complete. The data obtained from the KYTC vehicle was more flexible and allowed more accurate and detailed analysis than the data from the ARAN vehicle. The developed roughness data had a very weak correlation with the rideability ratings and no definitive quantitative measure was obtained from this relationship. The regression analysis performed explained a maximum of 53.9% of the variability between rideability ratings and roughness measurements.

The International Roughness Index is very capable of quantifying roughness of highway pavements, but it does not seem to measure the roughness associated with railroad crossing surface deterioration. Another drawback of this statistic is its use of a moving 25 foot average for determining the roughness value from profiles. Future research is necessary to create a roughness index capable of determining roughness over short distances for smaller scale applications like railroad crossings. This report hypothesizes that a roughness index that considers vertical axle acceleration in addition to vertical passenger acceleration and tire loading would produce a greater correlation between roughness and rideability.

As previously mentioned, it would be advantageous if this measurement was capable of distinguishing roughness caused by the different components of a railroad-highway grade crossing: the highway pavement, pavement approaches and the crossing surface. Figure 4.3 displays these different components of a typical railroad crossing. The responsibility of each component should be mentioned as well; the highway owner is responsible for the highway pavement surface, vertical geometry, the angle at which the highway intersects the railway and the pavement approaches. Both the highway owner and railway owner have a shared interest in the railroad crossing surface and the railroad company is solely responsible for the roughness associated with the superelevation of the track.

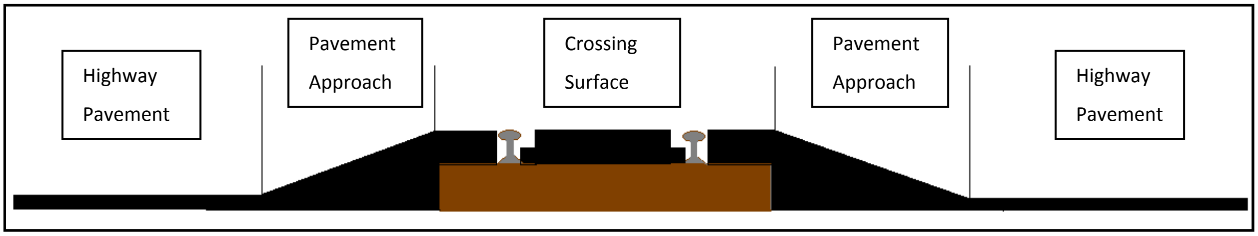

Figure 4.3 Railroad Crossing Components

A quantitative measure of railroad-highway at-grade crossing roughness will allow transportation officials to create a prioritized list of projects for rehabilitation or construction. This tool will be valuable both highway transportation officials and railroad company officials for maintaining their infrastructure.   This standard, rapid and user-friendly method will give a rational reason to maintain or upgrade poor railroad-highway crossings, while potentially improving safety and ride quality and reducing life-cycle costs.

CHAPTER 5. AASHTO QUESTIONNAIRE RESULTS

5.1 STATE SURVEY OF RAILROAD CROSSING ROUGHNESS PROCEDURES

A questionnaire was created to examine the procedures, if any, that each state employed for determining railroad crossing roughness. Questionnaires were distributed to every state in the US, including the Commonwealth of Puerto Rico. There were forty-two responses returned. These responses were broken down into three categories by what type of method each state had for determining the roughness of a rail/highway crossing. These three categories are: no method, by inspection (visual and objective), and by quantitative analysis.

Many state agencies have no method for evaluating the roughness of railroad crossings. These states include Alabama, Arizona, California, Hawaii, Indiana, Kansas, Maryland, Massachusetts, Montana, New Hampshire, New Mexico, North Dakota, Ohio, Pennsylvania, South Carolina, Utah, Vermont, Virginia, Wisconsin, and Wyoming. Kentucky is also included but is currently seeking methods through this research.

The majority of states that responded to the questionnaire employed methods of evaluating crossing roughness by inspection, including visual, objective or both aspects. States that had these methods are Arkansas, Connecticut, Delaware, Florida, Illinois, Idaho, Iowa, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New Jersey, Oregon, South Dakota, Tennessee, Texas, and Washington. Procedures used by these states include sending teams out to the site to inspect the crossings, normally giving them a rating based on their condition, have on-site reviews every few years, and by noting the elevation of the rails compared to the roadbed, which should be nearly flush. Tennessee reported that a one-half deviation between the rails and the roadbed bring complaints by the public.

The inspection by Connecticut is qualitative only, giving crossings ratings of poor, poor/fair, fair, and good. New Jersey has a method where they give the surface condition an evaluation based by a priority rating. This procedure includes evaluating drivability at posted speed, potholes, patching, rail pumping, surface unevenness, and vehicle maneuverability. These ratings are then used in a formula, along with values assigned for average daily traffic, to evaluate the surface condition rating.

No state that returned a survey indicated that they have a quantitative analysis method for determining the roughness of rail and highway crossings. Many states use certain formulas to determine a rating for roughness, but those are entirely objective. The states that use a quantitative measure for prioritizing maintenance or new construction of crossings do not have a measure to quantify roughness; their methods are based on average daily traffic numbers, sight distance, safety devices in-place and train traffic, the crossing surface ratings are of an objective nature. Completed questionnaire results is found in Appendix A of this report.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The initial attempt concluded that the inertial profilers would obtain fairly accurate profile measurements but these results were restricted to crossings that were reasonably smooth. The Face Rolling Dipstick used in the initial attempt also developed similar results to the inertial profilers but proved to not be as effective due to crossing traffic interruptions while taking measurements and difficulty in developing an IRI value. The Roughometer II proved to be ineffective because the Roughometer does not measure actual surface profiles. It was concluded that the IRI values did not measure accurately at shorter distances which are typical of railroad-highway at-grade crossings.

The follow-up attempt concluded that inertial profilers provide no definitive quantitative measure of roughness. This is due to a regression analysis of 59.3% variability between rideability ratings and roughness measurements. Three disadvantages of measuring railroad-highway at-grade crossing roughness with inertial profilers were: Laser profilers measure features that do not affect rideability, but these features do contribute to calculated roughness values. Inertial Profilers are much more adept at measuring and analyzing data from profiles over longer distances. Typically these vehicles do not test sections any shorter than one-fourth mile in length, being as such, their sampling intervals are too long to evaluate roughness over short distances such as railroad crossings. IRI does not take into account vertical axle acceleration nor does it correlate well with this factor.

6.2 RECOMMENDATIONS

Since the inertial profilers used in this report were not effective at measuring the railroad-highway at-grade crossings due to the short distances of the crossing profile, three alternatives are proposed:

1. Australian Road Research Board Walking Profiler G2 – World Bank Class 1 instrument with a sampling interval of 9.5 inches and a +/- 6.3 in/mile IRI accuracy.

2. CS 8800 Walking Profiler – World Bank Class 1 instrument and ASTM E950 equivalent device that is capable of measuring profiles at shorter distances (Sampling 1 inch intervals) and a +/- 3 in/mile IRI accuracy. It is designed for precise detection of areas of localized roughness.

3. ENSCO Portable Ride Quality Measurement System – This device is placed inside of the vehicle and uses two linear accelerometers that calculate the horizontal and vertical displacements that occur while going over the crossing. These displacements can be further used to derive a value for roughness.

It is proposed to continue this research based on **Phase Two** findings. The proposal is to calculate the vertical wheel velocity functions of the vehicle as it passes over the crossing to ultimately predict the vibration levels that occurred. It is the ultimate goal to deliver a computer program that will allow engineers to input a roughness profile and obtain as output, the expected vehicle vibration levels as a function of vehicle speed and vehicle type. Similar alternatives could be proposed in order to establish rideability ratings for railroad crossings.

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APPENDIX A

AASHTO Questionnaire Results

State	Received	#1	#2	#3	#4	#5	#6	#7	#8
Alabama	YES	No	No		No	No	No	No	
Alaska	NO								
Arizona	YES	No	No		No	No	No	No	
Arkansas	YES	Yes, see attached procedure for investigating railroad crossing surfaces. Also attached is a railroad crossing investigation team report form used to inspect a crossing surface	No		No	No	No	No	
California	YES	No	No		No	No	No	No	
Colorado	NO								
Connecticut	YES	Yes, the state of Connecticut is currently in the process of updating its railroad/highway at-grade crossing inventory. Crossing information, such as type of crossing surface and condition of crossing surface is contained as part of the inventory. Visual examination of the crossing surface during field inspections of the crossing as well as performing vehicle test-runs over the crossing, determines the adequacy/rideability of the crossing surface.	No, all crossing are reviewed the same way. The inventory contains all crossing no matter the route classification.	Vehicle	No	No	In addition to evaluating the condition of the crossing itself, a determination as to whether or not a crossing is "humped" or "dip" is included as part of the inventory.	No	

Delaware	YES	Yes. Review team rides all crossings same passenger in vehicle.	No.		Subjective by review team (excellent, good, fair, poor)	See Answer 4	Yes	No	-
Florida	YES	No, Computerized/laser procedure is in the experimental stages. Empirical approach is currently being used.	No. It is a subjective process: the rated condition addresses the expected remaining surface life in relation to the predicted actual use of the crossing. For example, one crossing surface may show visual distress, yet receive a functionally adequate rati		Yes	No. A portion is subjective and portion is objective.	No. the approach and leave for 100 feet on local roads are considered measured as crossing. State highways approach/leave is 200 feet. All measures are from centerline to edge of rail. Skew crossings distance are from perpendicular line off tangent rail ine intersect at edge of pavement.	Yes, Available on FDOT Rail Office website. Www.myflorida.com/fdot/railoffice	Our website has study on use of laser for humped crossing measurement.
Georgia	NO								
Hawaii	YES	No	No		No	No	No	No	
Idaho	YES	Yes, we measure the roughness of roadways with a profiler can, but because a RR crossing's roughness is averaged within a tenth mile segment, specific crossing roughness is not distinguishable. Therefore we physically inventory all RR crossings, evaluating their roughness as an operation contributor.	No	None, Field inspection only.	No	-	Yes, Both the approaches and the crossing surface (concrete, rubber, wood) are evaluated for their effect on vehicle speeds and safety.	No	-

Illinois	YES	Yes	No		Yes, See Response	No	No	No	For more information on 92 Illinois Administrative Code 1535 see: www.ilga.gov/commission/jcar/admincode/092/09201535sections.html
Indiana	YES	NO	NO		No	No	Yes	No	This subject is largely ignored because the Railroad's are generally legally obligated to make repairs when necessary. Most evaluations of condition are purely subjective and random owing to personal experience or complaints.
Iowa	YES	No. Primary highway crossings are monitored by railroads, field Iowa DOT personnel, and Iowa DOT Rail Office Inspector	The cities and counties would monitor crossings under their jurisdiction.		No		Yes. Inspected for condition and track to roadway elevation difference. We determine if the roadway can be profiled to smooth the approach section, or if it requires a track raise/rebuild due to poor track condition.	No.	-
Kansas	YES	No	Yes, state highways only		No	No	No	No	
Kentucky	YES	No	No		No	No	No	No	

Louisiana	YES	Not really. We do a field review for our RR inventory. The crossing is rated good, fair, or poor in this inventory. We have a web photo log of the state highway of state maintained highways too.	Yes as to their classification in the inventory, but they are still rated good, fair, or poor.	No	No	No	Yes. They are looked at as part of the whole issue, but the crossings are usually evaluated separately because we will deal directly with the RR for the surface.	Louisiana did some crossing stability research ~20 years ago. Dr. Rose had a copy of our old report. Nothing to my knowledge has been done recently. We have done some special crossings surfaces and are looking at them.	Hope this helps. Please let me know if you have any questions or need additional info.
Maine	NO								
Maryland	YES (2)	No	No		No	No	No	No	
Massachusetts	YES	No	No		No	No	No	No	
Michigan	YES	Yes. State inspectors perform on-site reviews of all public highway-railroad grade crossings approximately once every two years.	No. All crossings are rated on a scale of one (1) to five (5), with one (1) being a crossing surface in new/excellent condition and five (5) being a crossing in poor/failing condition.		No. It is a subjective process: the rated condition addresses the expected remaining surface life in relation to the predicted actual use of the crossing. For example, one crossing surface may show visual distress, yet receive a functionally adequate rating for lower speed and volume of expected daily traffic, while another crossing may have equal visual distress, but due to greater anticipated speed and volume of daily traffic it may not warrant a functionally adequate rating.	No	Yes. Crossing surfaces are rated according to specific surface material guidelines such as condition of rail, timber, rubber panels, concrete, etc., while roadway approaches are rated in relation to roadway deterioration elements such as quantity, type and severity of cracks, potholes, rutting, etc.	Yes. In 2002 our program was requested to research "best practices" in crossing surface repair, which resulted in a multi-state survey, the production of a draft report and the formation of a task force to study the issue further. The draft report is an unofficial document issued to members of the task force and to our initial survey respondents. Dr. Jerry Rose of the University of Kentucky's Department of Civil Engineering participates in our task force efforts and should have a copy of this draft document.	Questions regarding the crossing inspection process should be directed to Tina Hissong, Rail Safety Manager @ 517-335-2592 or hissongt@michigan.gov Questions regarding crossing surface and roadway approach inspection guidelines should be directed to Brett Kach, PE, Trunkline Crossing Engineer @ 517-335-2272 or kachb@michigan.gov Questions regarding the draft research paper on this topic should be directed to Kris Foondle, Local Crossing Analyst @ 517-335-3054 or foondlek@michigan.gov

Minnesota	YES	No we have no specific "procedure" - roughness is subjective - if it feels rough it is rough	see above answer		No	No	no	no	We consider crossing surfaces to be the responsibility of the local road authority and the railroad. Our office facilitates communication between these two entities if there is a complaint. We install new surfaces on state highways when there is road construction.
Mississippi	YES	Grade crossing roughness is subjectively evaluated by our rail inspectors in the course of the annual inspection cycle of all crossings, and during diagnostic inspections on an as required basis.	The inspection is visual and objective only.		Yes, but it is not used in the evaluation of grade crossings.	NA	Yes, the approaches and the crossings are evaluated and reported separately. Deficiencies on the approaches are reported to the appropriate jurisdiction of the roadway, and the crossing surface deficiencies to the railroad.	No	-
Missouri	YES	Yes, We are mostly complaint driven, but we compare the crossing to the existing road and if it is rougher (ride quality) than existing road it must be repaired.	No		No - we send a state inspector on-site and they drive the crossing and make a judgement call.	No	Yes, we will determine if it is a local road authority problem or a railroad problem and then notify the correct party.	No	
Montana	YES	No	No		No	No	No	No	No

Nebraska	YES	Yes, we have a policy set up in our rules and regulations concerning crossing surface and safety. Nebraska Department of Roads rules may be seen at our Department website at: www.dor.state.ne.us under Rail and Public Transportation Division and then Rail Rules and Regulations	No		Yes, when the crossing is 2 inches higher or lower thatn the approach roadway, then it needs to have maintenance to bring it back into compliance.	No	Yes, if the approach is bad, then that would need to be adjusted the same as the crossing. If there is an improvement to the approach, the it would have to meet the requirements to be within 1/2 inch of the crossing surface after the imporvement.	No	
Nevada	YES	Yes, we evaulate crossing visually with a team of 3 or 4 raters and then take an average of their reviews.	No		No	No	No	No	
New Hampshire	YES	NH evaluates and prioritizes grade crossing projects based upon numerous factors including input from municipalities and railroads operating over the crossing. We do not use quantitative measures of roughness.	na	na	no	na	No, our approach is to minimize the project to 50' to the crossing. With this method both surfaces are evaluated together.	No	NH is very interested in the results of this project and look forward to receiving the report. Please email me with questions or inforamtion as it becomes available.
New Jersey	YES	Yes, Each crossing surface is rated 1-5 (5 is worst). Items evaluated include: driveability at posted speed, potholes, patching, rail pumping, surface unevenness, manuevering vehicles	No, All crossings are the state's jurisdiction and all are scored against each other, with high ADT given additional points.	Vehicle, Level, Rulers	Surface Condition Rating = A+B. A=Surface Condition Value (1=30...5=70), B=ADT (<1600=0, 10,000-18,500=18, >60,000=30)	Yes, the surface rating in assigned by one of our railroad inspectors	Yes, we have only had to repair the approaches to restore the overall ride to the crossing. For the overall score it is combined into one. Crossings that have approach problems are so noted for additional review.	No	

New Mexico	YES	No, but NMDOT does measure highways and intersections for smoothness and sometimes rail crossings are included in the process, but this information is not used for any other purpose other than roadway evaluations.	NA		No	NA	Yes	No	-
New York	NO								
North Carolina	YES	No	No		No	No	No	No	-
North Dakota	YES	No	No		No	No	No	No	
Ohio	YES	No	No		No	No	No	No	
Oklahoma	NO								
Oregon	YES								
Pennsylvania	YES	No	No		No	No	No	No	
Rhode Island	NO								
South Carolina	YES	No, we do not have a formal procedure. We do have railroad crossing inspectors who will advise if a crossing is rough (their actual job is for inventory and sight distance). We will then request that the railroad fix the problem. Other than that we rely on our maintenance engineers and public notification.	No		No	No	No	No	

South Dakota	YES	Yes, a visual inspection from which quantitative number is given for rideability.	No, the state inspects all public crossings per federal requirements for crossing inventory.	None	a 1-9 value assigned, with 9 being best.	Yes, objective only	Yes and No, crossing surface is evaluated separate with 1-9 value (9 being excellent). Highway approaches and crossing surface evaluated together as rideability. Highway approaches are not evaluated.	Yes, railroad crossing study prepared by Terje Preber, Mohan Ballagere, Krishna Prasad was prepared and published in 1992 (January 31,1992) as report SD90-14-E1 and SD90-14-F2; possible copy can be obtained from Office of Research, SD DOT, 700 E. Broadway, Pierre, SD 57501	-
Tennessee	YES	Yes, TDOT uses Inspection Teams to physically visit crossings. The Physical inspection can be a result of a citizens complaint or an inspector generated regular inspection.	No	Inspector Rides vehicle over crossing at posted speeds to evaluate vehicles response. After construction or modification of a crossing the department often traverses the crossing with a Low-Boy Trailer to check clearances on State Routes only.	Yes, based on experience the State of Tennessee has found that 1/2 inch of deviation/deterioration of crossing surface brings a public complaint or dissatisfaction.	Inspectors are independent of Railraod and Highway Maintenance staff. However, the evaluation is conditional with Material, Type, Geometry, etc.	No, They are considered together (see TCA 65-3-103)	No	
Texas	YES	Yes, we utilize a crossing submission form.	No. Only public crossings located on the State Highway System are eligible.				Answer: Yes. Evaluation of crossiong surface conditions is somewhat subjective. We have an evaluation form which identifies several evaluation factors; however, the prioritization and selection of crossing locations for replanking is done on a cost per vehicle basis.	Texas Transportation Institute at Texas A&M University has conducted research in this area; however, it was many years ago (1980s), and while we looked at using some of the rating information, we never really implemented it for making project funding decisions. I also do not have a research report number for you.	Please contact me if you want a copy of our "crossing submission form
Utah	YES	No	No		No	NO	No	No	-

Vermont	YES	No, by state statute the state is responsible for repair, replacement and maintenance of the highway surface through all public crossings. We have a small amount of state-only funds available each year to address surfaces on a first come first serve basis. We work to with the railroads and our maintenance districts to try to prioritize which surfaces need to be worked on any given year. Many times it is based upon how many complaints have been received from the public.	No	NA	No		No	No	-
Virginia	YES	No	No		No	No	No	No	
Washington	YES	Yes, see WAC 480-62-225.	No		No	No	No	No	
West Virginia	NO								

Wisconson	YES	No	No	No	No	No	Yes	No	While we don't have a separate set of criteria for different roadways, question #3, it should be noted that we do have a program that is funded with state dollars to repair crossings on the State Trunk Highway (STH) system. The STH systems includes federal and state numbered routes. Being a subjective analysis, the speed of the highway is also taken into consideration when determining if a crossing needs to be repaired or replaced. A crossing that rides OK for a 25 mph city street might not be smooth enough for a 55 mph rural highway. There is also a legal process for a community to address rough crossings. Local units of are able to petition the Office of the Commissioner of Railroads for them to hold a hearing and make a determination on the crossing and if need be, Order the railroad to repair/replace the crossing.
Wyoming	YES	No	No		No	No	No	No	

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