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EVALUATION OF PERFORMANCE OF LIGHT-WEIGHT PROFILOMETERS

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16 Abstract

Several lightweight, non-contact profilometers (LWP) are now available to measure profiles of newly constructed Portland Cement Concrete Pavement (PCCP). As constructed smoothness measurements by four LWP's and the California-type profilograph were collected on four new PCCP sections on I-70 in Kansas. The LWP's were: Ames Engineering LISA, K. J. Law T6400, ICC ATV LWP, and SSI LWP. Smoothness measurements were also made by two high-speed profilometers, K. J. Law's T6600 and KDOT's South Dakota profilometer made by ICC. The data was statistically analyzed in the Analysis of Variance (ANOVA) and the Least Square Means (LSMeans) approaches.

The lightweight profilers showed statistically similar Profile Index (PI) values when performing as the California-type profilograph. The lightweight profilers reported slightly higher PI than the manual California-type profilograph using ProScan to electronically reduce the traces.

The International Roughness Index (IRI) values reported by LISA, T6400, and ICC ATV were statistically similar. Significant differences were observed in some cases when comparing the values obtained from the South Dakota and T6600 high-speed profilometers and SSI LWP.

Variable coefficients of determination, R^2, values were obtained when performing a linear regression analysis of the PI and IRI data for the individual profilers and for all sections tested by a given profiler. No reasonably consistent correlation between PI and IRI was established.

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Several lightweight, non-contact profilometers (LWP) are now available to measure profiles of newly constructed Portland Cement Concrete Pavements (PCCP). As-constructed smoothness measurements by four LWP's and the California-type profilograph were done on four newly constructed PCCP sections in Kansas. The LWP's are: Ames Engineering LISA, K. J. Law T6400, ICC ATV LWP and SSI LWP. Smoothness measurements by two high speed profilers, KDOT South Dakota profilometer and K. J. Law T6600, were also made. Data was statistically analyzed in the Analysis of Variance (ANOVA) and the Least Squares Means (LSMeans) approaches. The lightweight profilometers showed statistically similar Profile Index (PI) values as the California-type profilograph. However, on average, the California-type profilograph reported lower PI values on most of the sections, especially on the driving lane. The International Roughness Index (IRI) values reported by LISA, T6400 and ICC ATV were statistically similar. The South Dakota type profiler reported statistically similar IRI values to those reported by the LWP's and the K. J. Law T 6600 in most of the cases. However, significant differences were observed in some cases when compared with the K. J. Law T6600 profiler and SSI LWP. Variable coefficients of determination, R^2, values were obtained by doing a linear regression analysis between the PI's from the LWP's and those from the California-Type Profilograph. Correlation analyses were also done with the PI and IRI data for the individual and all sections for a given profiler. The relationship between these smoothness statistics appeared to be not only site-specific but also equipment-dependent.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PHOTOS

LIST OF FIGURES

INTRODUCTION

The smoothness of newly constructed concrete pavements is a major concern in the highway industry. As-constructed smoothness needs to be evaluated to examine the quality since it affects the road users directly. If it is possible to quickly evaluate the profile of the newly paved surface, corrective action may be taken before next day's paving resulting in substantial savings for the contractor. This largely has motivated the innovation of pavement profile measuring devices which can measure "true" profile of the pavements quickly. Several lightweight non-contact profilometers (LWP) are now available to measure profiles of newly constructed Portland Cement Concrete Pavements (PCCP). LWP's have the advantage of profiling pavements faster and more efficiently. The on-board computer gives immediate results. The system also generates a "profilograph-type" plot with defect and "must-grind" locations, which indicates where the roughness exists and what corrective action needs to be taken. In addition to recording pavement profile data, the on-board computer can also compute a variety of roughness summary statistics. A majority of states currently use profilometers to report roughness in International Roughness Index (IRI) for the network-level survey. If the as-constructed smoothness can be measured with LWP's in terms of IRI, then the IRI could be treated as a "cradle-to-grave" type statistics for road roughness. This was found to be desirable in an earlier study of road roughness (*1*).

OBJECTIVE

The major objective of this study was to compare as-constructed smoothness measurements by the Lightweight Profilometers and the KDOT California-type profilograph on newly constructed PCCP's. The study also looked at the smoothness measurements by the high speed profilers, such as, KDOT South Dakota profilometer and K. J. Law T6600, to investigate whether the IRI statistics can be used as a "cradle-to-grave" statistics for road roughness.

TEST SECTION LAYOUT AND DATA COLLECTION

Profile data was collected on selected, newly-built PCCP sections using the following lightweight profilometers: (i) Ames Engineering LISA, (ii) K. J. Law T 6400, (iii) International Cybernautics Corporation (ICC) Light Weight Profiler and (iv) Surface Systems and Instruments (SSI) Light Weight Profiler. The KDOT South Dakota Profiler, K.J. Law T6600 Profiler and the Ames Engineering California-type profilograph were also used in data collection. Four sections on Interstate route, I-70 were selected in this study. The sections are located west of Topeka, east of K-99 Wamego exit, west of McDowell Creek Road exit, and at Exit 318. The sections were yet to be opened to traffic at the time of testing. Table 1 lists the locations of the test sections and the type of equipment used. I-70 is a four lane divided highway. Three of the sections were located in the west bound lanes and one section in the east bound lanes. All sections except Exit 318 were about four miles long, and two sites were selected on each section at the ends as shown in Figure 1. The Exit 318 section was about two mile long. Data was collected on two consecutive 528-ft test segments without structures or other break in the paving. At least three passes/runs on each section were made by each profiler except the California-type profilograph, which was run only once. The ICC LWP was used for data collection on the Topeka, Wamego and McDowell Creek Road sections. The Ames LISA was used on the Topeka and Wamego sections. The K. J. Law T6400 was used only on the Topeka section. The SSI profiler was used only on the Exit 318 section. The contractors reported as-built Profile Index (PI) results. The as-constructed smoothness values, obtained with a "zero" blanking band, are summarized in Table 2. The PI values ranged from 15.2 in/mile to about 33.6 in/mile. According to the KDOT Special Provisions 90P- 111-R3, the sections were in bonus

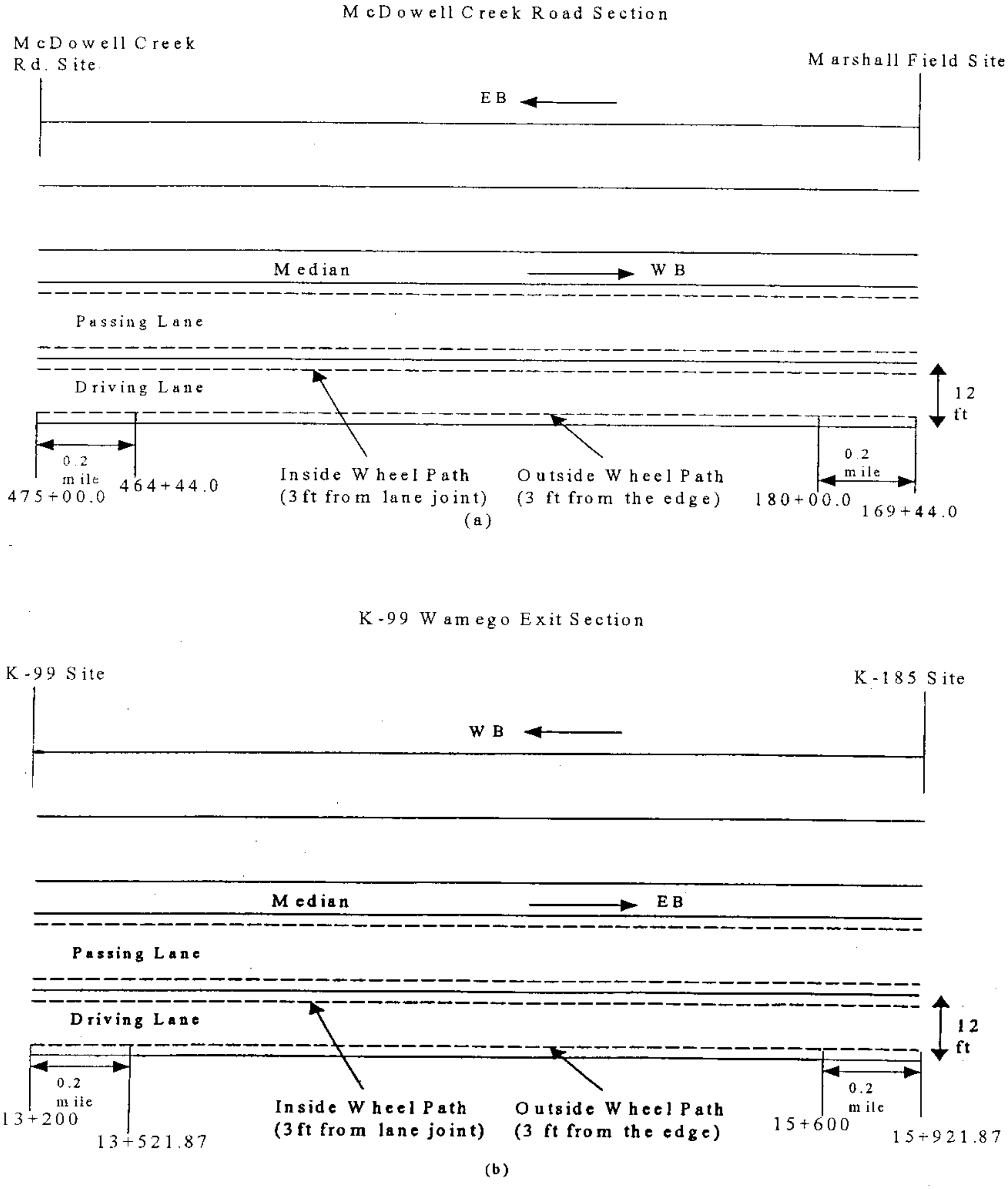
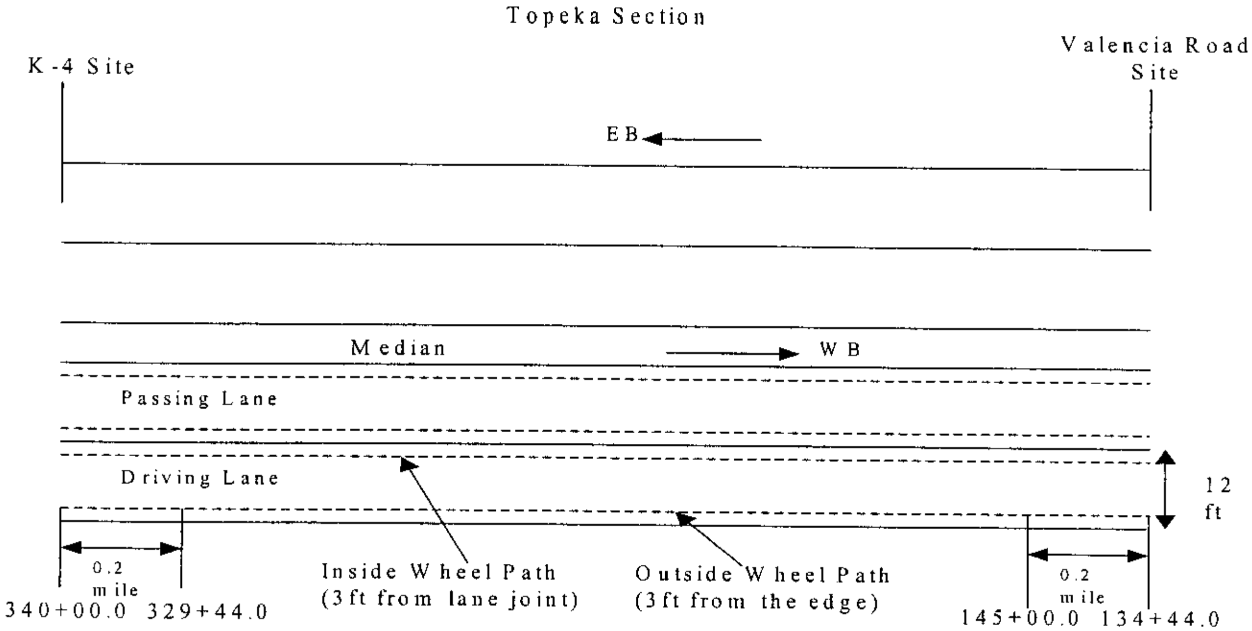


Figure 1:Layout of the Test Sections (a) I-70, McDowell Creek Road, (b) I-70, K-99 Wamego Exit



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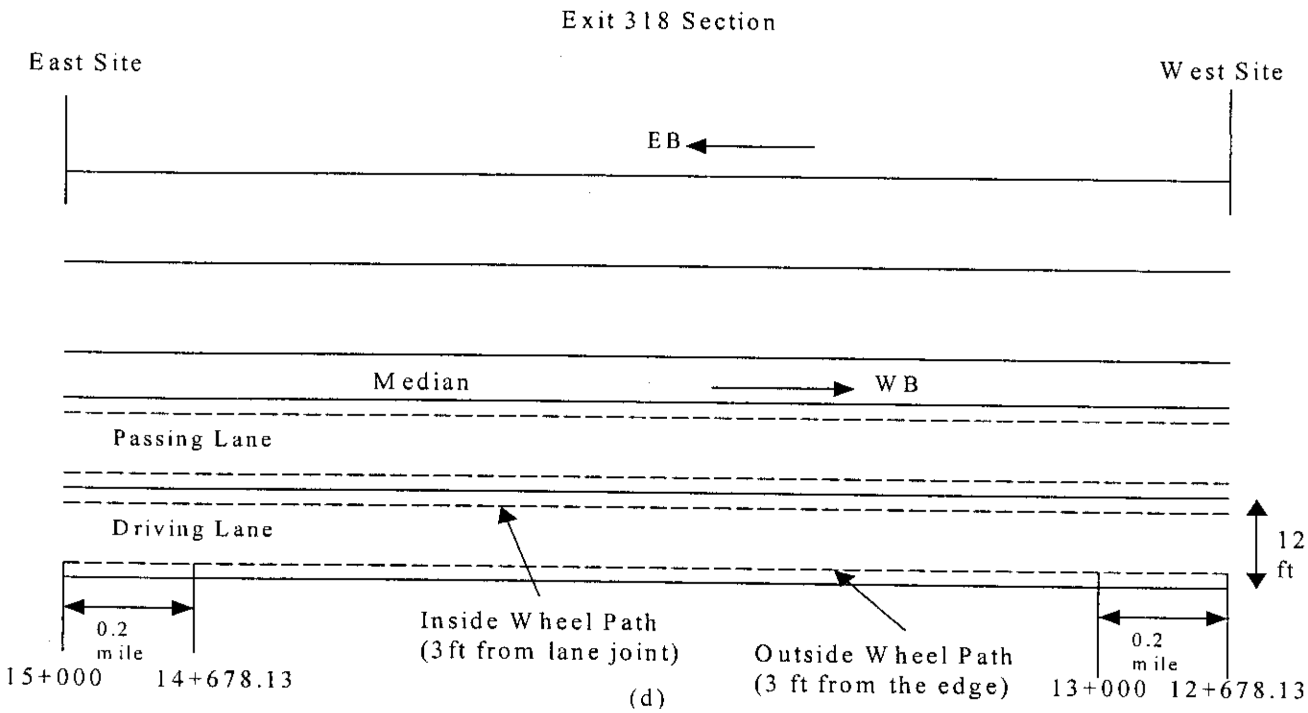

(d)

Figure 1:Layout of the Test Sections (c) I-70, Topeka Section, (d) I-70, Near Exit 318 (Contd..)

TABLE 1 Location of the Test Sections and Type of Equipment Used

	Location Description							
	McDowell Creek Road (K-5086-01) Date: 10/3/99		K-99 Wamego Exit (K-5628-01) Date: 10/15/99		Topeka Section (K-5087-01) Date: 11/17/99		I-70, 318 Exit (K-1143-01) Date: 6/15/00	
Profiler Type & Description	Sta. 475+00.0 to Sta. 464+44.0	Sta. 180+00.0 to Sta. 169+44.0	Sta. 13+200 to Sta. 13+521.87	Sta.15+600 to Sta. 15+921.87	Sta. 134+44.0 to Sta. 145+00.0	Sta. 340+00.0 to Sta. 329 +44.0	Sta. 13+000 to Sta. 12+678.13	Sta. 15+000 to Sta. 14+678.13
KDOT California Type Profilograph	X	X	X	X	X	X	X	X
Ames Lightweight (LISA)			X	X	X	X		
KJ Law Lightweight (T6400)					X	X		
KJ Law Van (T6600)					X	X		
KDOT South Dakota Profiler	X	X	X	X	X	X	X	X
Original Contractor CA Profilograph	X	X	X	X	X	X	X	X
Shilling Lightweight (ICC)	X	X	X	X	X	X		
SSI Profilometer							X	X

TABLE 2 Test Section Characteristics (Contractor data)

Route	Section	Length (miles)	Station		Date Constructed	PI Range (in/mile)	As-Constructed Avg. PI (in/mile)
			Begin	End			
I-70	Topeka, Valencia	0.366	132+91.0	152+22.0	10/8/99	17.4 to 30.4	23.36
	Topeka, K-4	0.596	360+10.0	328+62.5	10/23/99	15.5 to 29.4	24.68
I-70	Wamego Exit, K-99	0.186	13+200	13+300	9/10/99	12.22 to 20.4	15.24
	Wamego Exit, K-185	0.101	15+000	15+325	9/22/99	14.45 to 18.88	16.99
I-70	McDowell Creek Road	0.606	480+92.0	448+91.5	9/13/99	12.2 to 33.6	19.97
	Marshall Field	0.789	204+92.0	163+25.5	7/2/99	13.5 to 27.1	24.5
I-70	Exit 318, Station 13+000	0.1243	12+993.0	13+393.0	5/12/00	11.72 to 25.85	18.79
	Exit 318, Station 15+000	0.1245	14+993.0	15+393.7	5/10/00	10.45 to 24.33	17.39

to full-pay range. On average, the K-185 Wamego Exit site was a bonus site and all others were full-pay sites.

EQUIPMENT DESCRIPTION

Details of several lightweight non-contact profilometers and their features are described below.

Ames Lightweight Inertial Surface Analyzer (LISA)

The LISA is a laser mounted profiler based on a John Deer Gator utility vehicle. This vehicle has operating speed ranging from 5 to 15.5 mph. LISA has an effective ground pressure of only 6 psi with a 200 lb operator. It is marketed by AMES Engineering Inc. of Ames, Iowa for measuring smoothness on new or existing asphalt and concrete surfaces. The system meets the requirements of an ASTM E950 Class1 road profile measuring device. It has a simple and easy menu driven IBM-compatible computer system. The system is insensitive to the ambient light and temperature conditions. The on-board computer has the odometer mode, which is used to locate bumps and "must grind " line quickly. LISA can calculate a variety of roughness statistics including PI and IRI. It can measure profiles with wavelengths varying from 0.5 ft to 200 ft with 0.1% horizontal accuracy. The output is either a true profile or a "trace" like that produced by the California-type profilograph. Data can be stored on the standard 3 ½ inches IBM compatible floppy disk (*2*). Photo 1 shows LISA in operating mode.

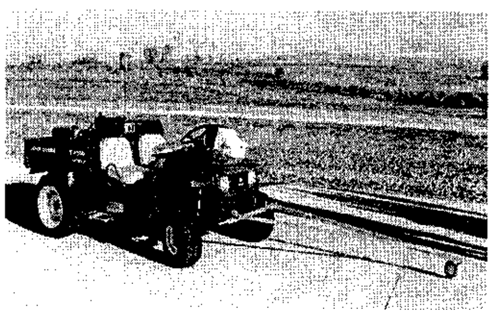

Photo 1 Ames Engineering LISA

K.J. Law T6400 Lightweight Profilometer

The T6400 Lightweight Profilometer, manufactured by K.J. Law Engineers, Inc. of Novi, Mich., is a single infrared sensor system mounted on a Kowasaki chassis. T6400 meets all the requirements of an ASTM E950 class 1 road profiling device. The profiler is designed to profile uncured concrete or freshly laid asphalt. True profile and a host of roughness indexes can be displayed on the system monitor or plotted on the printer. It has the flexibility to store data permanently and copy to a floppy disk. A digital encoder provides the distance pulses to clock the computer for calculating the spatial profile, the distance traveled, and the test speed. The system has precision accelerometer, non-contact sensor and photocell for start-end detection and events. It also has a digital distance encoder (*3*). Photo 2 shows the K. J. Law T6400 Lightweight Profilometer.

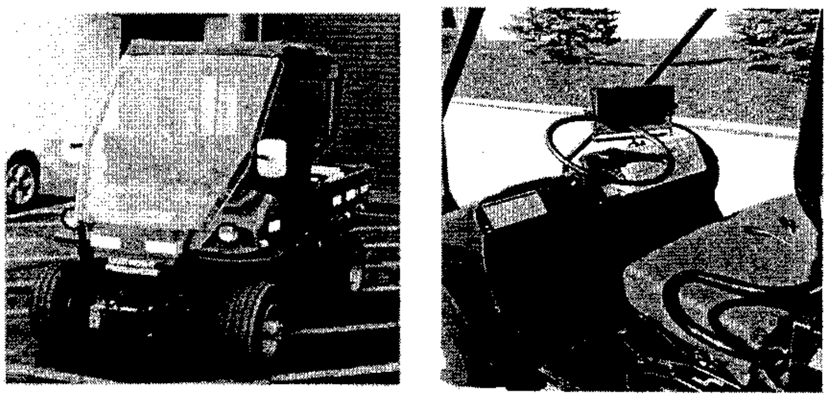

Photo 2 K. J. Law T6400 Lightweight Profilometer

International Cybernetics Corporation (ICC) Lightweight Profiler

The ICC light-weight profiler uses an infrared laser and precision accelerometer to obtain profile measurements. The system consists of an industrial quality PC with an IBM graphics printer, precision accelerometer, laser height sensor, data acquisition sub-system, photocell for start-end detecting, and distance measuring instrument (DMI). The collected raw data is processed and the results are output in standard or metric units on the flat panel display or graphics printer. The ICC lightweight profilometer uses the profile measurements to calculate a variety of roughness indices, such as, PI, IRI and RN. It also generates a "profilograph-type" plot with defect locations and must grind lines. The profiler is mounted on an all-terrain vehicle (ATV) with very low tire pressures (3 to 4 psi) or similar chassis so that it can test pavements almost immediately after paving. The system meets the requirements of an ASTM E950 Class 1 profiling device. The data collected is not affected by vehicle variation (i.e. speed, weight and suspension). In this study, data was collected at vehicle (ATV) speed of 25 to 30 mph. Photo 3 shows the ICC lightweight profilometer.

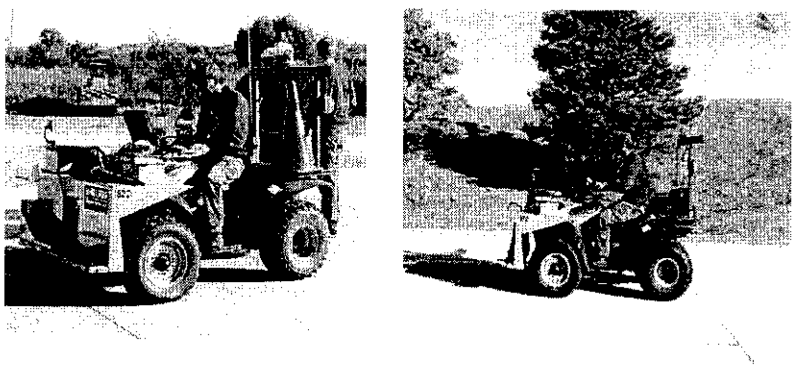

Photo 3 International Cybernetics Corporation (ICC) Lightweight Profiler

Surface Systems and Instruments (SSI) Light Weight Profiler

This light weight profiler has recently been marketed by SSI, Inc. of Sausalito, Calif. The system meets the requirements of an ASTM E950 Class I profiling device. It uses an infrared laser sensor and precision accelerometer to obtain the profile of a newly paved concrete or bituminous pavement. The model tested in this study was based on an Ingersoll-Rand Carryall electric vehicle, although a gasoline engine model is also available. The model tested had a single laser sensor with distance measurement using a side-mounted fifth wheel in line with the rear wheels of the vehicle. The bicycle-style wheel was found to provide more precise distance measurements than the vehicle tires when using a digital encoder and does not require re-calibration with any changes in the environmental conditions or vehicle operators. The operating speed of the SSI light weight profiler varies from 3 to 20 mph depending upon the vehicle selected. The SSI system offers bi-directional, dual wheel path testing with a single sensor or a profiler with dual sensors. The SSI LWP has a "back-and-go" data acquisition system which allows immediate starting and stopping of data collection. The SSI Profiler uses the profile measurements to calculate a variety of roughness statistics, such as, PI, IRI, and RN. It also has the capability to simulate the California-type profilograph and to generate a multiple wheel path plot with defect locations and "must grind" lines. The SSI software has a MS Windows interface with on-screen viewing of data collection, actual profile traces, and reports(5).

 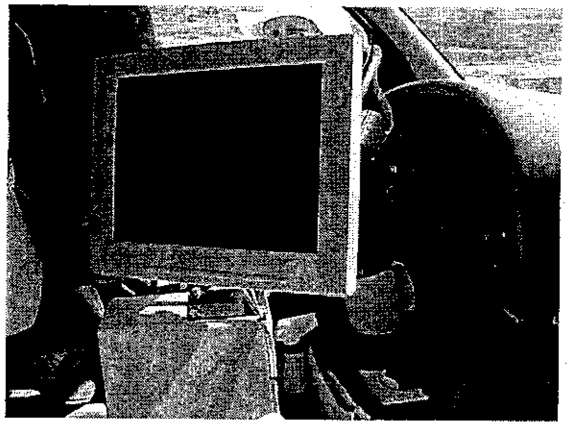

Photo 4 Surface System and Instruments (SSI) Lightweight Profiler

TEST SECTION DESCRIPTION

Detail descriptions of all four sections are given below.

McDowell Creek Road

The two sites tested on this section are McDowell Creek Road and Marshall Field. The weather on the test date was partly cloudy with temperatures in the mid 50's. A fairly strong southerly breeze at 10 to 15 mph was blowing. Data was collected on both lanes of the west bound direction. A layout of the section is shown in Figure 1(a). At the McDowell Creek Road site, tests were conducted from station 475+00.0 to 464+44.0 and at the Marshall Field site from 180+00.0 to 169+44.0.

K-99 Wamego Exit

The condition at the time of testing on this site was quite warm with temperatures from low to mid 60's. The day was mostly sunny with a few clouds. The wind was blowing from the north at 0-5 mph. On this section, data was collected on the east bound lanes from station 13+200 to 13+521.87 near

K-99 exit and from station 15+600 to 15+921.87 near K-185 exit. Figure 1(b) shows both sites of the section.

Topeka Section

The test day was sunny and quite warm. Temperature rose to mid 50's. The wind was blowing from variable direction between North and East at 0-5 mph. Data was collected on the west bound lanes. The layout of this section is shown in the Figure 1(c). On the K-4 site, data was collected from station 340+00.0 to 329+44.0 and on the Valencia Road site from station 145+00.0 to 134+44.0.

Exit 318 Section

The test day was sunny and quite warm. Temperature rose to mid 80's. The wind was blowing from variable direction at 0-10 mph. Data was collected on the west bound lanes. The layout of this section is shown in the Figure 1(d). On the West site, data was collected from station 13+000 to 12+678.13 and on the East site from 15+000 to 14+678.13.

RESULTS AND DISCUSSION

Table 3 presents the summary statistics of the PI and IRI measurements on all sections for all equipment types. Figures 2 and 3 illustrate the PI and IRI results, respectively. At the Valencia site of the Topeka section, the mean PI varied from 22.5 in/mile to 25.3 in/mile. The PI value from the KDOT Ames profilograph, reported by the ProScan software, showed the highest PI and AMES LISA had the lowest. The ICC ATV appeared to have the closest PI when compared with the KDOT California-type profilograph with an absolute difference of 0.8 in/mile. The mean IRI varied from 85.5 in/mile to 92.6 in/mile, with the highest value for the KDOT South Dakota profilometer and the lowest for the K.J. Law T6600 Road Surveyor. For the K-4 site, the mean PI varied from 20.2 in/mile to 22 in/mile with the highest and lowest PI values for the ICC ATV and AMES LISA,

TABLE 3 Summary of the PI and IRI values

Section	Lane	Mean IRI (in/mile)						Mean PI (in/mile)						
		K.J. Law T6400	K.J. Law T6600	ICC ATV	AMES LISA	SSI	KDOT SD Profilometer	K.J. Law T6400	K.J. Law T6500	ICC ATV	AMES LISA	SSI	KDOT SD Profilometer	KDOT Profilograph
I-70, Valenica	Driving Lane	102.0	96.0	102.2	101.1		105.4	28.3	27.2	29.7	26.2		35.5	30.0
	Passing Lane	75.8	74.9	73.8	74.6		79.7	20.2	19.3	19.3	18.7		26.7	20.6
I-70, K-4	Driving Lane	96.9	93.2	98.8	102.5		101.5	24.4	23.4	26.1	24.2		36.9	23.8
	Passing Lane	71.9	73.4	74.3	74.6		76.4	16.3	17.3	18.0	16.2		27.1	18.3
I-70, K-99	Driving Lane			71.7	71.5		67.7			23.2	23.4		27.0	20.7
	Passing Lane			71.8	74.8		71.3			22.6	22.1		27.4	22.6
I-70, K-185	Driving Lane			68.7	66.6		68.2			20.0	18.7		23.1	16.6
	Passing Lane			66.3	68.9		65.7			18.0	16.6		22.1	17.5
I-70, McDowell Creek Road	Driving Lane			121.8			119.0			32.2			41.0	23.6
	Passing Lane			94.2			95.5			23.0			32.4	30.5
I-70, Marshall Field	Driving Lane			112.0			108.5			29.5			38.0	29.3
	Passing Lane			105.3			101.7			31.0			35.5	29.0
I-70, Exit 318: Station 13+000(West)	Driving Lane					94.6	77.7					25.6	24.9	23.0
	Passing Lane					85.9	77.3					20.4	23.4	19.9
I-70, Exit 318: Station 15+000 (East)	Driving Lane					86.9	83.5					22.8	26.7	20.8
	Passing Lane					85.5	78.3					20.6	24.3	19.1

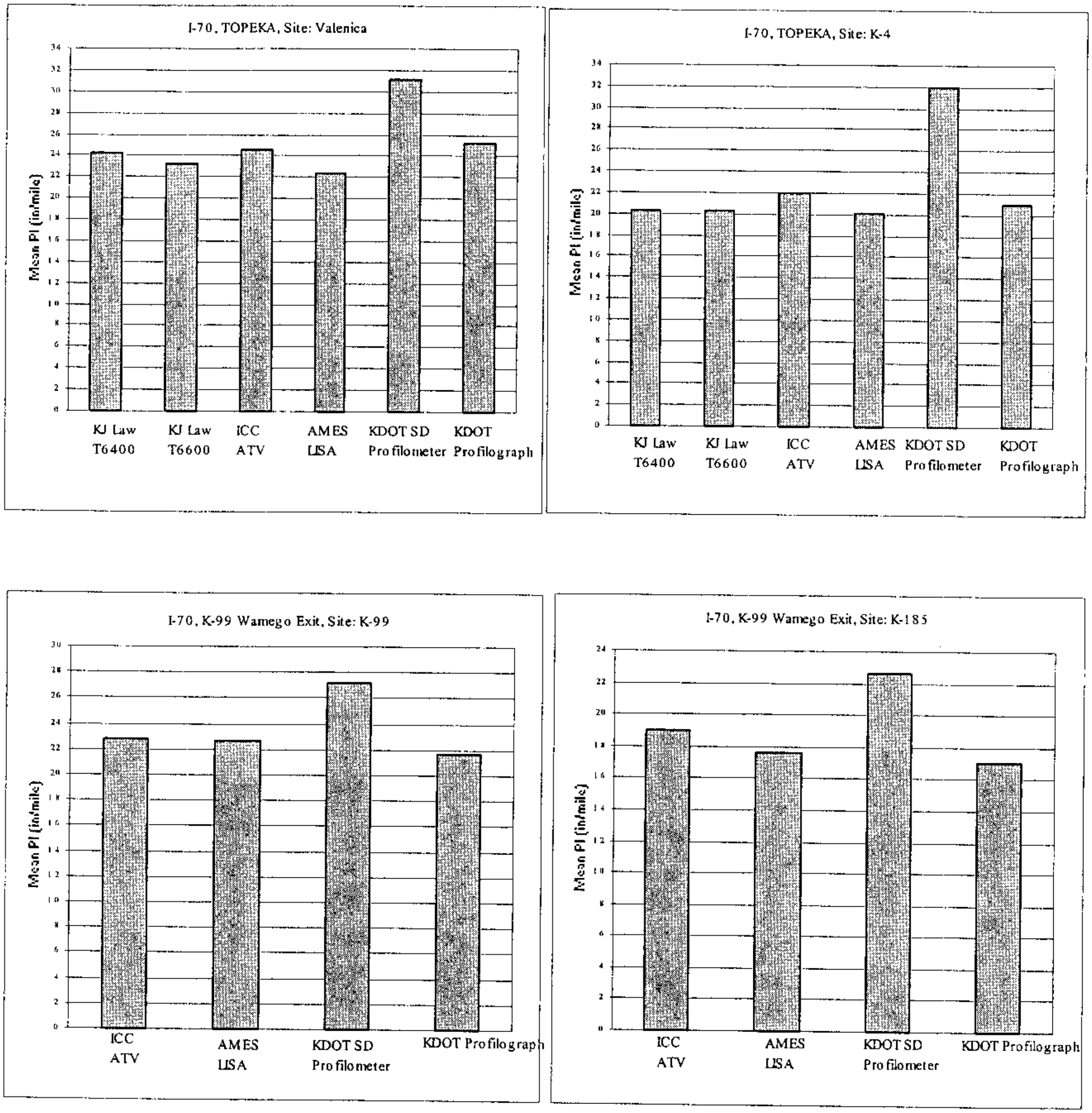

Figure 2: PI for Individual Section

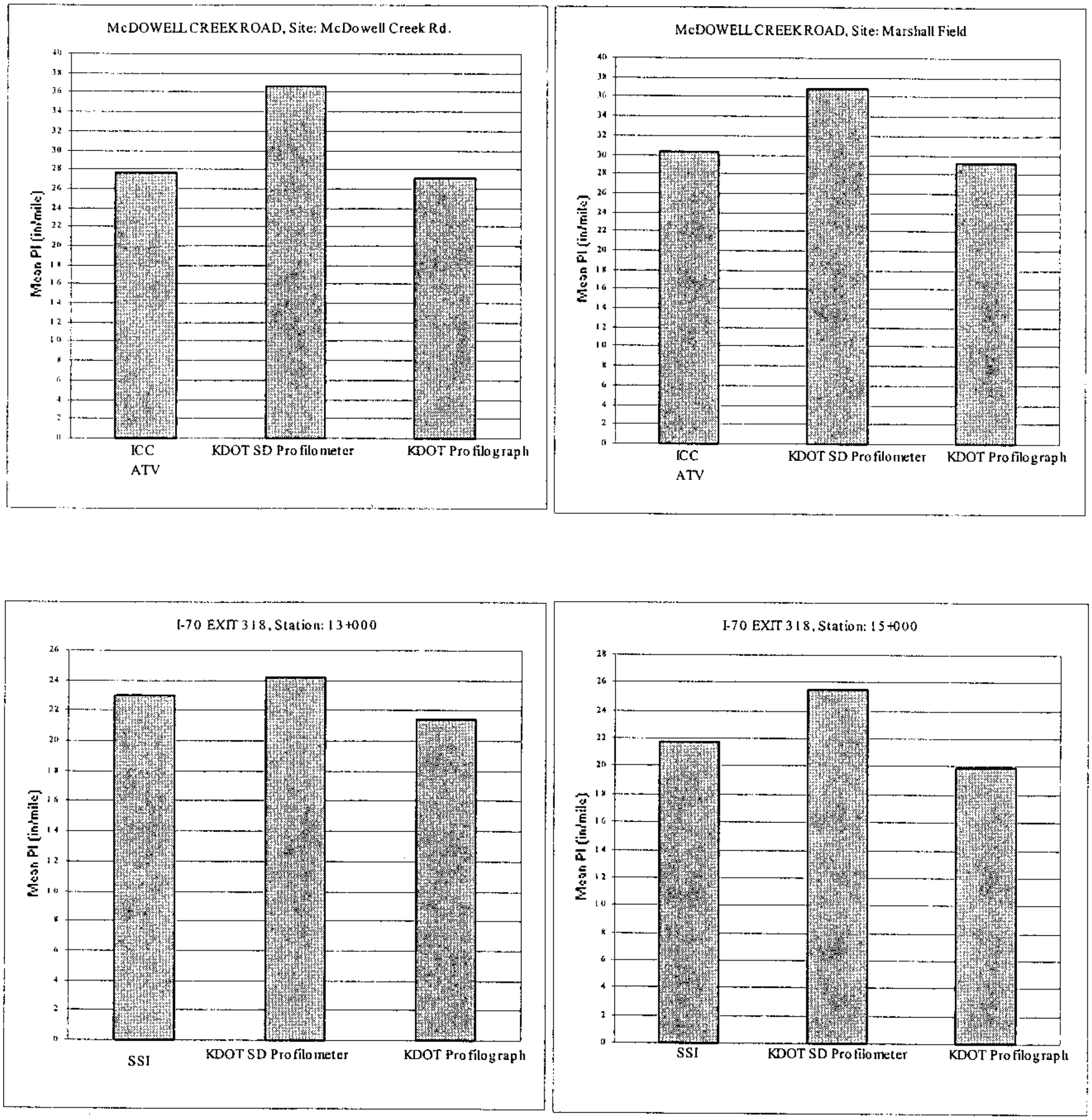

Figure 2: PI for Individual Section (Contd...)

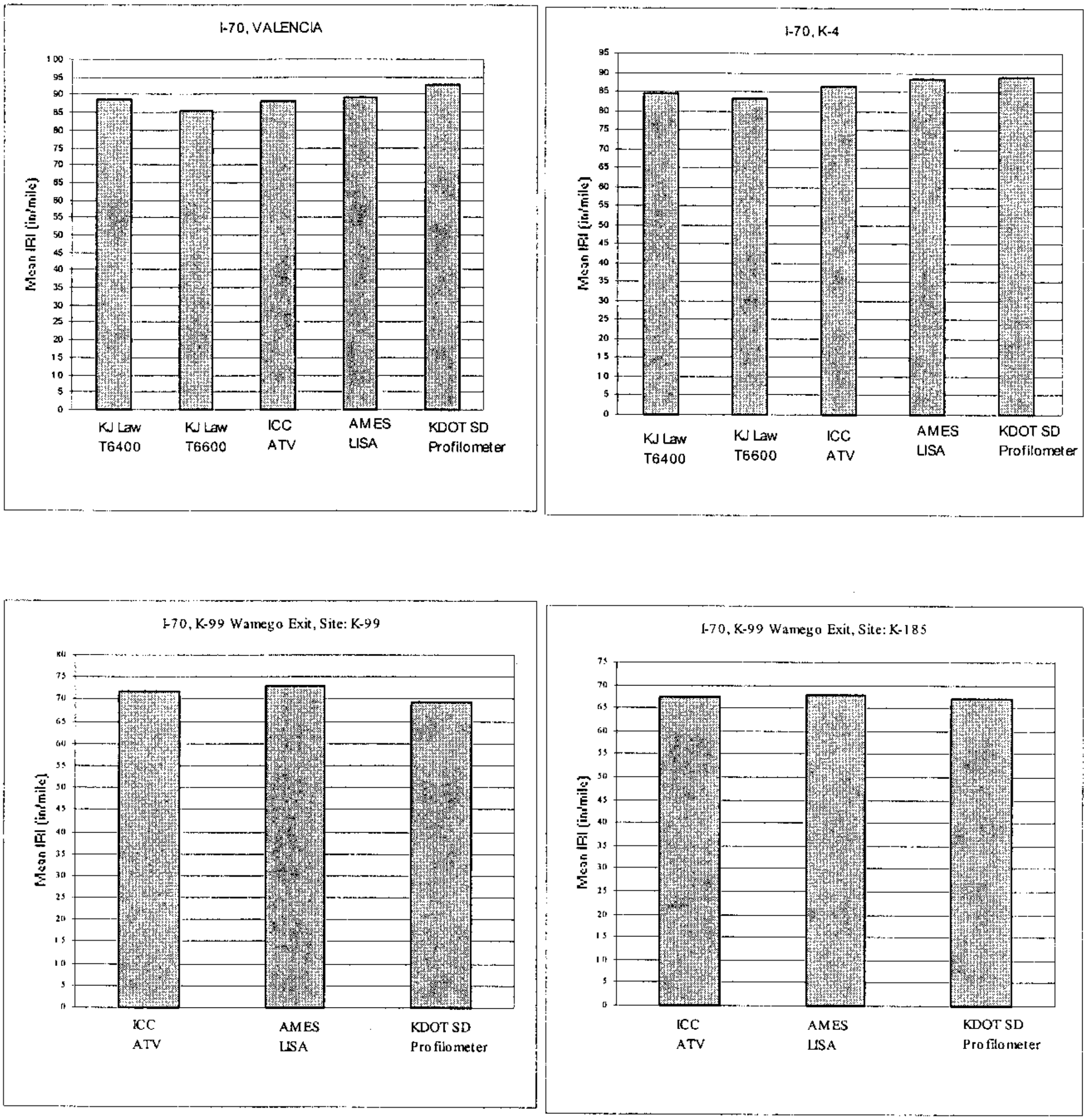

Figure 3: IRI for Individual Section

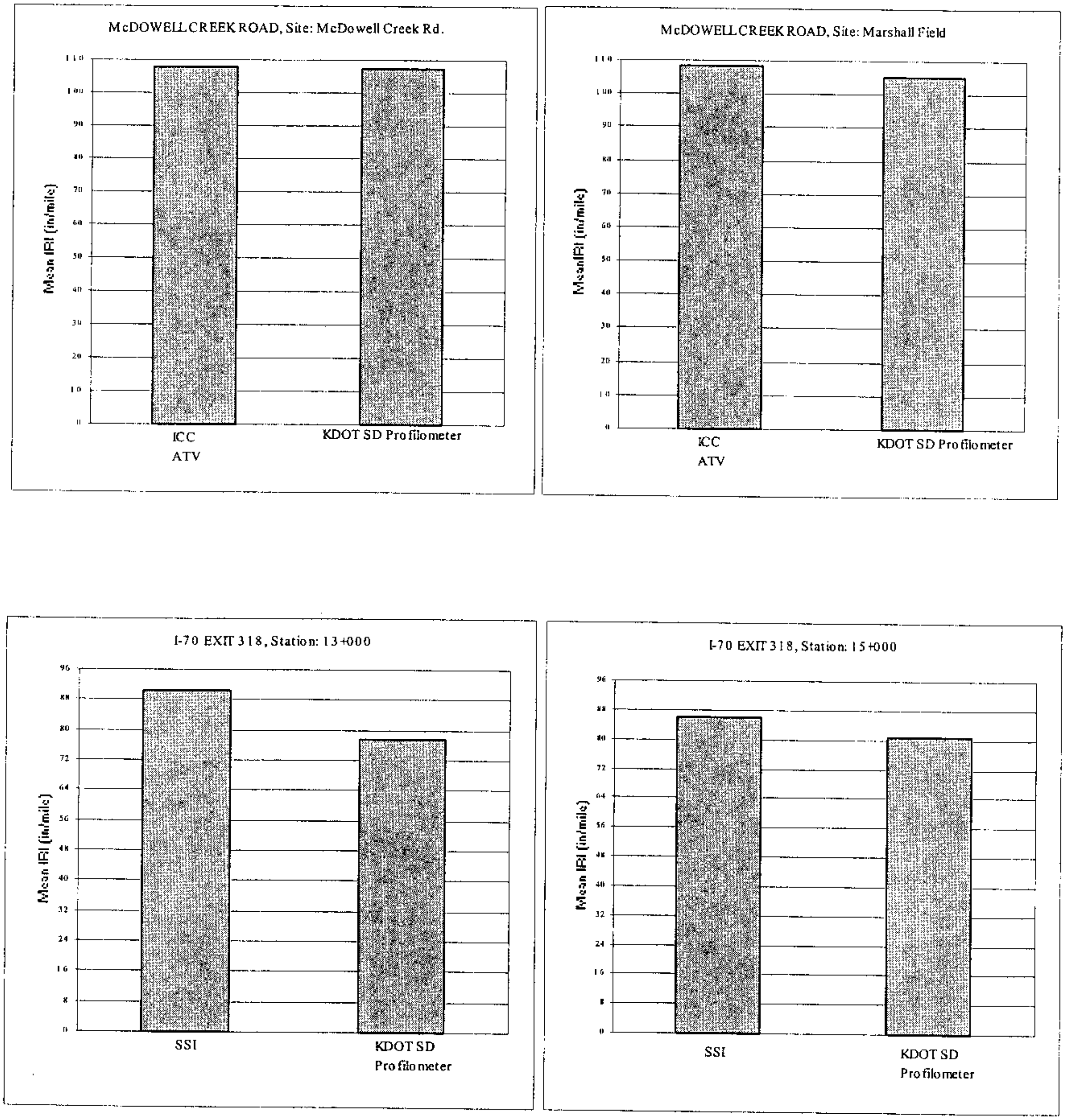

Figure 3: IRI for Individual Section (Contd..)

respectively. The ICC ATV has the closest PI when compared with the KDOT California-Type profilograph with an absolute difference of 0.9 in/mile. The mean IRI varied from 83.3 in/mile to 88.9 in/mile.

On the K-99 Wamego Exit section, AMES LISA has the mean PI closest to the KDOT profilograph for both sites. The differences are 1.1 in/mile and 0.5 in/mile for the K-99 and K-185 sites, respectively.

The ICC ATV is the only light-weight profiler tested on the McDowell Creek Road section. It reported mean PI values of 27.6 in/mile and 30.2 in/mile for the McDowell Creek Road and Marshall Field site, respectively. These values are slightly different (0.5 in/mile and 1.1 in/mile) when compared with the PI's from the KDOT profilograph.

On Exit 318 section, SSI has higher PI for both sites than the KDOT Ames profilograph. PI's on the passing lane are closer than the PI's on the driving lane. This phenomenon has also been observed on the Topeka site for Ames LISA. It is to be noted that these pavement sections are sloped toward the median for surface drainage. It is possible that the profilograph measurements are affected by the cross slope on the driving lane. This phenomenon should be investigated further. The IRI values appeared to be more variable. The KDOT South Dakota-type profilometer measured higher IRI for all segments than any other measurement device on the Topeka section. The IRI's reported by the K.J. Law T6600 van were lower than KDOT profilometer IRI on almost all lanes of the Topeka section. On the driving lane of the Valencia site, the mean IRI of K.J. Law T6600 was much higher than the KDOT profilometer IRI. This was not expected since both are high speed-type profilers. Lower IRI than the light weight profilometers were reported by the KDOT South Dakota-type profiler on the other sections. On the Exit 318 West section, KDOT South Dakota-type profiler had much lower mean IRI than the SSI LWP IRI on three out of the four lanes at the two sites. This may happen because of the difference in speeds at which the measurements were taken. The KDOT South Dakota-type profiler was operated at about the highway speed (50 mph) whereas the SSI was run at 5-10 mph.

STATISTICAL ANALYSIS

Analysis of Variance (ANOVA)

Comparison among all equipment tested in this study was done using the Analysis of Variance (ANOVA) technique and the SAS software (6). It is to be noted that an unequal number of smoothness measurements were obtained for different profilometers. The LWP's made three runs and the two high-speed profiler vans (KDOT SD Profilometer and the K. J. Law T6600) made five runs on each site. The KDOT California-type Profilograph was run only once on each wheel path (track) because the measurements were very time consuming. As stated earlier, not every piece of equipment was available for testing on all sites. Thus, in statistical terms, the experiments were "unbalanced" designs. The ANOVA was done by taking the least squares means (LSMean) approach with a Type III analysis. This approach weighs the estimates of each treatment or treatment combination effect equally, but not each observation (7). LSMean model deals with the average of individual treatment measurements and for treatment combination, it gives unequal weight to each observation. The effects of one or more factors on treatments for comparison are eliminated since it estimates the average of the averages. It may be mentioned here that increased sample size increases the precision of the estimate of the treatment combination mean response (7). There are five independent variables in this experimental problem: 1. Segment (two, 0.1 mile sections), 2. Track (left or right wheel path), 3. Lane (passing or driving), 4. Site (within a test section) and 5. Equipment.

The analysis for each section was done in two steps. The first step was a four-way ANOVA, which measured the changes in a three-way interaction across the levels of the fourth factor. In this case, the fourth factor was "segment." The model for the four-way ANOVA was:

$$R_{ijkl} = Trt_i + Lane_j + Track_k + Seg_l + \varepsilon_{ijkl}$$

where, R = Response/Smoothness measurement;

Trt_i = ith Equipment effect;

$Lane_j$ = jth Lane effect;

$Track_k$ = kth Track effect;

Seg_l = lth Segment effect; and

ε = Error terms.

Thus, the above test was done to see whether there were any significant differences in the equipment-lane-track interaction across the levels of the segment (two 0.1 mile sections).

The second test was done by eliminating the "segment" effect in a three-way ANOVA. Like the four-way ANOVA, three-way ANOVA measured the changes in a two-way (equipment-lane) interaction across the levels of the third factor (track or wheel path). Model for the three-way ANOVA was:

$$R_{ijk} = Trt_i + Lane_j + Track_k + \varepsilon_{ijk}$$

Table 4 shows the results of tests of the fixed effects for the three-way ANOVA. The results indicate that the track effect was not very significant and it also has negligible interaction with the lane. Tests were also performed to check if there were any variations in responses between the measurements on the two sites of a test section reported by each equipment. The MIXED procedure was followed in ANOVA where the factors, equipment, lane, track and segment were set as "fixed" effect, and the site as "random effect."

TABLE 4 Tests of Fixed Effects

Source	NDF	Type III F	Pr > F*
Treatment/Equipment type**	4	0.27	0.8834
Lane	1	33.63	0.0001
Treatment*Lane	4	3.82	0.0082
Track	1	6.05	0.017
Treatment*Track	4	1.07	0.3804
Lane*Track	1	4.38	0.0411
Treatment*Lane*Track	4	0.16	0.9567

* Level of Significance, $\alpha = 5\%$
** Equipment type: 1. Ames LISA 2. KDOT California-type Profilograph 3. ICC ATV 4. K.J. Law T6400 & 5. K.J. Law T6600

The ANOVA tests were performed for both smoothness summary statistics, PI and IRI, on all four locations. Tables 5 thru 8 show the detailed results for the ANOVA analysis. As shown in Table 4, there was no significant difference in the equipment-lane-track interaction over the levels of factor "segment." The rejection region was set at 5% level of significance. It was also found from the two-way analysis with the equipment-lane interaction over the factor "track" that "track" (wheel path) has no significant effect on the equipment-lane interaction. Finally, the ANOVA was repeated to find the differences in response measurement by all equipment on each lane. This part of the test is of particular importance since this is the main issue of this study. Table 9 shows the summary results of the LSMeans analyses conducted with the PI values. There were no significant differences in the PI values obtained from the LWP's and the KDOT California-type profilograph on all sites.

Table 10 shows the results of the statistical analyses conducted with IRI values. The LWP's appeared to measure similar IRI on all sections. However, the KDOT South Dakota-type Profilometer

TABLE 5 Detailed ANOVA Results for the Test Sections on I-70 near Topeka

EQUIPMENT		LANE	PI Values		IRI Values	
			t-statistics	Pr > t	T-Statistics	Pr > t
Ames Lisa	KDOT Profilograph	1	-0.65	0.5286		
Ames Lisa	ICC ATV	1	-1.04	0.3197	0.34	0.7325
Ames Lisa	KDOT South Dakota	1	-4.44	0.0007	-0.43	0.667
Ames Lisa	K.J.Law T6400	1	-0.46	0.6558	0.62	0.5369
Ames Lisa	K.J.Law T6600	1	-0.05	0.9587	1.92	0.0599
KDOT Profilograph	ICC ATV	1	-0.39	0.7047		
KDOT Profilograph	KDOT South Dakota	1	-3.79	0.0023		
KDOT Profilograph	K.J.Law T6400	1	0.19	0.8512		
KDOT Profilograph	K.J.Law T6600	1	0.59	0.5623		
ICC ATV	KDOT South Dakota	1	-3.40	0.0048	-0.78	0.4409
ICC ATV	K.J.Law T6400	1	0.58	0.5727	0.28	0.7822
ICC ATV	K.J.Law T6600	1	0.98	0.3441	1.57	0.1206
KDOT South Dakota	K.J.Law T6400	1	3.98	0.0016	1.05	0.2963
KDOT South Dakota	K.J.Law T6600	1	4.38	0.0008	2.35	0.0221
K.J.Law T6400	K.J.Law T6600	1	0.4	0.6932	1.30	0.1996
Ames Lisa	KDOT Profilograph	2	-0.74	0.4698		
Ames Lisa	ICC ATV	2	-0.48	0.6421	0.14	0.8889
Ames Lisa	KDOT South Dakota	2	-3.58	0.0034	-0.91	0.3677
Ames Lisa	K.J.Law T6400	2	-0.29	0.7776	0.2	0.8442
Ames Lisa	K.J.Law T6600	2	-0.31	0.7621	0.12	0.9087
KDOT Profilograph	ICC ATV	2	0.27	0.7923		
KDOT Profilograph	KDOT South Dakota	2	-2.83	0.0143		
KDOT Profilograph	K.J.Law T6400	2	0.46	0.6558		
KDOT Profilograph	K.J.Law T6600	2	0.44	0.6704		
ICC ATV	KDOT South Dakota	2	-3.1	0.0085	-1.05	0.2989
ICC ATV	K.J.Law T6400	2	0.19	0.8543	0.06	0.9546
ICC ATV	K.J.Law T6600	2	0.17	0.8702	-0.03	0.98
KDOT South Dakota	K.J.Law T6400	2	3.29	0.006	1.1	0.2736
KDOT South Dakota	K.J.Law T6600	2	3.27	0.0062	1.02	0.3106
K.J.Law T6400	K.J.Law T6600	2	-0.02	0.9838	-0.08	0.9347

TABLE 6 Detailed ANOVA Results for the Test Sections at K-99 Wamego Exit

EQUIPMENT		LANE	PI Values		IRI Values	
			t-Statistics	Pr > t	t-Statistics	Pr > t
Ames Lisa	KDOT Profilograph	1	1.35	0.1831		
Ames Lisa	ICC ATV	1	-0.32	0.7489	-0.44	0.662
Ames Lisa	KDOT South Dakota	1	-2.27	0.0274	0.45	0.6523
KDOT Profilograph	ICC ATV	1	-1.67	0.1009		
KDOT Profilograph	KDOT South Dakota	1	-3.63	0.0007		
ICC ATV	KDOT South Dakota	1	-1.95	0.0567	0.9	0.3767
Ames Lisa	KDOT Profilograph	2	-0.41	0.6851		
Ames Lisa	ICC ATV	2	-0.55	0.5827	1.11	0.2733
Ames Lisa	KDOT South Dakota	2	-3.10	0.0032	1.35	0.1846
KDOT Profilograph	ICC ATV	2	-0.15	0.8851		
KDOT Profilograph	KDOT South Dakota	2	-2.69	0.0098		
ICC ATV	KDOT South Dakota	2	-2.55	0.014	0.24	0.8115

TABLE 7 Detailed ANOVA Results for the Test Sections at McDowell Creek Road

EQUIPMENT		LANE	PI Values		IRI Values	
			t-Statistics	Pr > t	t-Statistics	Pr > t
KDOT Profilograph	ICC ATV	1	-1.6	0.1192		
KDOT Profilograph	KDOT South Dakota	1	-4.6	0.0001		
ICC ATV	KDOT South Dakota	1	-3.0	0.0049	0.37	0.7139
KDOT Profilograph	ICC ATV	2	1.01	0.3215		
KDOT Profilograph	KDOT South Dakota	2	-1.49	0.1449		
ICC ATV	KDOT South Dakota	2	-2.5	0.0173	0.08	0.9391

TABLE 8 Detailed ANOVA Results for the Test Sections on I-70 near Exit 318

EQUIPMENT		LANE	PI Values		IRI Values	
			t-Statistics	Pr > t	t-Statistics	Pr > t
KDOT Profilograph	KDOT South Dakota	1	-2.22	0.0327		
KDOT Profilograph	SSI	1	-1.30	0.2006		
KDOT South Dakota	SSI	1	0.92	0.3653	-2.12	0.0443
KDOT Profilograph	KDOT South Dakota	2	-2.47	0.0184		
KDOT Profilograph	SSI	2	-0.57	0.5727		
KDOT South Dakota	SSI	2	1.90	0.0653	-1.65	0.1116

TABLE 9 Results of ANOVA with PI Values

Equipment		Lane		LSMean			
				Topeka	K-99 Wamego Exit	McDowell Creek Road	Exit 318
Ames LISA	KDOT-Profilograph	1	1	Equal	Equal		
Ames LISA	ICC ATV	1	1	Equal	Equal		
Ames LISA	KDOT- South Dakota	1	1	Not-Equal	Not-Equal		
Ames LISA	K. J. Law T6400	1	1	Equal			
Ames LISA	K. J. Law T6600	1	1	Equal			
KDOT-Profilograph	ICC ATV	1	1	Equal	Equal	Equal	
KDOT-Profilograph	KDOT- South Dakota	1	1	Not-Equal	Not-Equal	Not-Equal	Not-Equal
KDOT-Profilograph	K. J. Law T6400	1	1	Equal			
KDOT-Profilograph	K. J. Law T6600	1	1	Equal			
KDOT-Profilograph	SSI	1	1				Equal
ICC ATV	KDOT- South Dakota	1	1	Not -Equal	Equal	Not-Equal	
ICC ATV	K. J. Law T6400	1	1	Equal			
ICC ATV	K. J. Law T6600	1	1	Equal			
KDOT- South Dakota	K. J. Law T6400	1	1	Not-Equal			
KDOT- South Dakota	K. J. Law T6600	1	1	Not-Equal			
KDOT- South Dakota	SSI	1	1				Equal
K. J. Law T6400	K. J. Law T6600	1	1	Equal			
Ames LISA	KDOT-Profilograph	2	2	Equal	Equal		
Ames LISA	ICC ATV	2	2	Equal	Equal		
Ames LISA	KDOT- South Dakota	2	2	Not-Equal	Not-Equal		
Ames LISA	K. J. Law T6400	2	2	Equal			
Ames LISA	K. J. Law T6600	2	2	Equal			
KDOT-Profilograph	ICC ATV	2	2	Equal	Equal	Equal	
KDOT-Profilograph	KDOT- South Dakota	2	2	Not-Equal	Not-Equal	Equal	Not-Equal
KDOT-Profilograph	K. J. Law T6400	2	2	Equal			
KDOT-Profilograph	K. J. Law T6600	2	2	Equal			
KDOT-Profilograph	SSI	2	2				Equal
ICC ATV	KDOT- South Dakota	2	2	Not-Equal	Not-Equal	Not-Equal	
ICC ATV	K. J. Law T6400	2	2	Equal			
ICC ATV	K. J. Law T6600	2	2	Equal			
KDOT- South Dakota	K. J. Law T6400	2	2	Not-Equal			
KDOT- South Dakota	K. J. Law T6600	2	2	Not-Equal			
KDOT- South Dakota	SSI	2	2				Equal
K. J. Law T6400	K. J. Law T6600	2	2	Equal			

Note: Lane 1= Driving, Lane 2= Passing

TABLE 10 Results of ANOVA with IRI Values

Equipment		Lane		LSMean			
				Topeka	K-99 Wamego Exit	McDowell Creek Road	Exit 318
Ames LISA	KDOT South Dakota	1	1	Equal	Equal		
Ames LISA	ICC ATV	1	1	Equal	Equal		
Ames LISA	K. J. Law T6400	1	1	Equal			
Ames LISA	K.J. Law T6600	1	1	Equal			
KDOT South Dakota	ICC ATV	1	1	Equal	Equal	Equal	
KDOT South Dakota	K. J. Law T6400	1	1	Equal			
KDOT South Dakota	K. J. Law T6600	1	1	Not-Equal			
KDOT South Dakota	SSI	1	1				Not Equal
ICC ATV	K. J. Law T6400	1	1	Equal			
ICC ATV	K. J. Law T6600	1	1	Equal			
K. J. Law T6400	K. J. Law T6600	1	1	Equal			
Ames LISA	KDOT South Dakota	2	2	Equal	Equal		
Ames LISA	ICC ATV	2	2	Equal	Equal		
Ames LISA	K. J. Law T6400	2	2	Equal			
Ames LISA	K. J. Law T6600	2	2	Equal			
KDOT South Dakota	ICC ATV	2	2	Equal	Equal	Equal	
KDOT South Dakota	K. J. Law T6400	2	2	Equal			
KDOT South Dakota	K. J. Law T6600	2	2	Equal			
KDOT South Dakota	SSI	2	2				Equal
ICC ATV	K. J. Law T6400	2	2	Equal			
ICC ATV	K. J. Law T6600	2	2	Equal			
K. J. Law T6400	K. J. Law T6600	2	2	Equal			

Note: Lane 1= Driving, Lane 2= Passing

mean IRI values were statistically different than those reported by K. J. Law T6600 on the passing lane of the Topeka section. The mean SSI IRI's on the passing lane of the Exit 318 section were also different than those reported by the KDOT South Dakota-type Profilometer. This may indicate that high-speed measurements are not suitable for PCCP construction quality control.

Correlation between PI's from the LWP's and KDOT California-Type Profilograph

All LWP's studied can simulate the measurements by the California-type profilographs. Thus it was expected that the PI's from the LWP's will have a very high degree of correlation with the PI's from the Ames California-type profilograph results obtained in this study. Regression analyses were performed between the PI values obtained from different LWP's and PI values from the KDOT Ames profilograph. The equations obtained are shown in Table 11. For the K-185 Site, R^2 values varied from 0.552 (ICC ATV) to 0.705 (LISA). For the K-4 site, the R^2 values were 0.81 and 0.97 for the ICC LWP and K.J. Law T6400, respectively. Acceptable R^2 values were also obtained for the McDowell Creek Road and Exit 318 sites. The R^2 values are much lower for the sites Valencia Road, K-99 and Marshall Field. Regression analyses were also performed between the PI values from the KDOT South Dakota-type profilometer and the KDOT Ames Profilograph. Acceptable R^2 values were obtained for the McDowell Creek Road and K-4 sites.

Correlation between PI and IRI

Possible correlation between PI and IRI using data from the same site and the same profilometer was also investigated. The motivation was that if a relationship could be developed then the current as-built PCCP smoothness specifications of KDOT could be easily converted into IRI-based specifications. Table 12 lists the correlation relationships obtained. The general trend is PI increases with an increase in IRI values. The only exception was the K-99 Wamego Exit section for LISA. On

TABLE 11 Correlation between the PI's from the LWP's and the Ames Profilograph

Site	LWP	Equation	R^2
Marshall Field	ICC ATV	ICC PI = - 3.265 * Ames PI + 125.2	0.134
Marshall Field	KDOT SD	KDOT SD PI = -8.849*Ames PI + 294.5	0.28
McDowell Creek	ICC ATV	ICC PI = - 1.31 * Ames PI + 63.2	0.642
McDowell Creek	KDOT SD	KDOT SD PI = -1.234*Ames PI + 70.1	0.79
K-99	ICC ATV	ICC PI= -0.575* Ames PI + 35.3	0.385
K-99	LISA	LISA PI= -0.379* Ames PI + 30.9	0.122
K-99	KDOT SD	KDOT SD PI = 0.176*Ames PI + 23.4	0.233
K-185	ICC ATV	ICC PI= -1.49 * Ames PI + 44.4	0.552
K-185	LISA	LISA PI= -1.737* Ames PI + 47.3	0.705
K-185	KDOT SD	KDOT SD PI = -1.004*Ames PI + 39.7	0.165
Valencia	ICC ATV	ICC PI = 0.385 * Ames PI + 14.8	0.134
Valencia	LISA	LISA PI= 0.376* Ames PI + 13.0	0.228
Valencia	KJ Law 6400	KJ Law PI = 0.265* Ames PI + 17.6	0.1
Valencia	KDOT SD	KDOT SD PI = 0.275*Ames PI + 24.1	0.1
K-4	ICC ATV	ICC PI = 1.045 * Ames PI + 0.1	0.805
K-4	LISA	LISA PI = 1.048 * Ames PI - 1.8	0.806
K-4	KJ Law 6400	KJ Law PI = 1.302 * Ames PI - 6.98	0.967
K-4	KDOT SD	KDOT SD PI = 1.102*Ames PI + 8.9	0.649
Exit 318 East	SSI	SSI PI = 0.533 * Ames PI + 11.09	0.56
Exit 318 East	KDOT SD	KDOT SD PI = 0.066*Ames PI + 24.2	0.002
Exit 318 West	SSI	SSI PI= 0.922 * Ames PI + 3.19	0.65
Exit 318 West	KDOT SD	KDOT SD PI = -0.052*Ames PI + 25.3	0.004

TABLE 12 Site-by-Site Correlation between the PI and IRI

Site	LWP	Equation	R^2
Marshall Field	ICC ATV	PI = - 0.032 * IRI + 20.6	0.02
Marshall Field	KDOT SD	PI = 0.436 * IRI - 9.109	0.94
McDowell Creek	ICC ATV	PI = 0.032 * IRI + 20.6	0.02
McDowell Creek	KDOT SD	PI = 0.366 * IRI - 2.545	0.98
K-99	ICC ATV	PI= 0.032 * IRI + 20.6	0.02
K-99	LISA	PI= -0.0905* IRI+ 29.3	0.08
K-99	KDOT SD	PI = 0.165 * IRI + 15.72	0.34
K-185	ICC ATV	PI= -0.122 * IRI + 10.8	0.29
K-185	LISA	PI= -0.048* IRI + 20.92	0.05
K-185	KDOT SD	PI = 0.237 * IRI + 6.785	0.77
Valencia	ICC ATV	PI = 0.384 * IRI - 9.28	0.97
Valencia	LISA	PI = 0.307 * IRI - 4.46	0.97
Valencia	K. J. Law T6400	PI = 0.338 * IRI - 5.76	0.97
Valencia	K. J. Law T6600	PI = 0.392 * IRI - 10.246	0.98
Valencia	KDOT SD	PI = 0.378 * IRI - 3.864	0.89
K-4	ICC ATV	PI = 0.326 * IRI - 6.19	0.91
K-4	LISA	PI = 0.278 * IRI - 4.43	0.88
K-4	K. J. Law T6400	PI = 0.338 * IRI - 8.143	0.89
K-4	K. J. Law T6600	PI = 0.311 * IRI - 5.584	0.82
K-4	KDOT SD	PI = 0.365 * IRI - 0.402	0.91
Exit 318 East	SSI	PI = 0.374 * IRI - 9.28	0.97
Exit 318 East	KDOT SD	PI = 0.263 * IRI + 4.214	0.37
Exit 318 West	SSI	PI= 0.384* IRI - 9.28	0.97
Exit 318 West	KDOT SD	PI = 0.586 * IRI - 21.204	0.64

that section, PI decreased with an increase in IRI. The coefficient of determination, R^2, values are much higher for all profilers on the Topeka section. Lower R^2 were obtained on the two other sections, K-99 Wamego Exit and McDowell Creek Road. SSI relationships are very good for the Exit 318 section. This may indicate that it may not be realistic to correlate PI with IRI. Both IRI and PI are the results of the mathematical transforms that respond differently to the sinusoids of different wavelengths. Also, they are calculated using different algorithms. It is to be noted that a completely different scenario was observed on the K-4 site. On that site, the individual relationships between PI and IRI for the driving and passing lanes showed low R^2 values. But when all data points were aggregated, the R^2 value improved significantly. This may indicate that the relationship is more site-specific than being universally true.

Regression analysis was also done for each piece of equipment taking data from all sites. For each light-weight profiler, the PI data obtained for all three runs on each track on each lane on every segment was used in this analysis, The equations obtained are shown in Table 13. The R^2 values vary widely. The K.J. Law T4600 LWP showed the highest R^2 value and the SSI LWP had the lowest R^2 value. It should be noted that the K.J. Law T4600 LWP was run only on the Topeka section and the SSI LWP only on the Exit 318 section. The ICC LWP was run on the Topeka, the McDowell Creek Road, and the Wamego Exit sections. For the vans, K.J. Law T6600 and the KDOT South Dakota profilometer, relationships between PI and IRI were very good. The KDOT South Dakota profiler was run on all four sections. These results may also indicate that the relationship between PI and IRI is not only site-specific but also equipment-dependent. A consistent correlation between PI and IRI was not established for a given profiler on multiple sites nor for a given site with multiple profilers.

TABLE 13 Correlation between the PI and IRI for each Equipment type

LWP	Equation	R^2
ICC ATV	PI = 0.253 * IRI + 2.05	0.829
LISA	PI = 0.196 * IRI + 5.17	0.525
K. J. Law T6400	PI= 0.349 * IRI - 7.91	0.893
SSI	PI= 0.206* IRI+ 4.16	0.298
K. J. Law T6600	PI= 0.356* IRI- 8.311	0.840
KDOT South Dakota Profilometer	PI= 0.350* IRI- 0.624	0.874

CONCLUSIONS

As-constructed smoothness measurements by the four Lightweight Profilomaters (LWP) and the KDOT California-type profilograph were compared on four newly constructed PCCP sections. The LWP's are: Ames Engineering LISA, K. J. Law T6400, ICC ATV LWP and SSI LWP. Smoothness measurements by the high speed profilers, KDOT South Dakota profilometer and K. J. Law T6600, were also made and compared. Based on the statistical analysis, the following conclusions can be drawn:

(i) The lightweight profilometers tested tended to produce statistically similar Profile Index (PI) values when compared with the California-type profilograph. The level of significance was set at 5%. However, on average, the Ames manual California-type profilograph, using ProScan to evaluate the traces, reported lower PI values on most of the sections, especially on the driving lane.

(ii) The International Roughness Index (IRI) values reported by LISA, T6400 and ICC ATV were statistically similar. Here also, the significance level was set at 5%.

(iii) The South Dakota type profiler reported statistically similar IRI values to those reported by the

LWP's in most of the cases. However, significant differences were observed when compared with the K. J. Law T6600 profiler and SSI LWP.

(iv) Variable coefficients of determination, R^2, values were obtained by doing a linear regression analysis between the PI's from the LWP's and those from the California-Type Profilograph.

(iv) Correlation analysis of the PI and IRI data from the same site and the same profilometer resulted in relationships that appeared to be more site-specific than being universal. The relationship between PI and IRI also appeared to be equipment-dependent when data for all sections was analyzed for a given profiler. No consistent correlation between PI and IRI was established.

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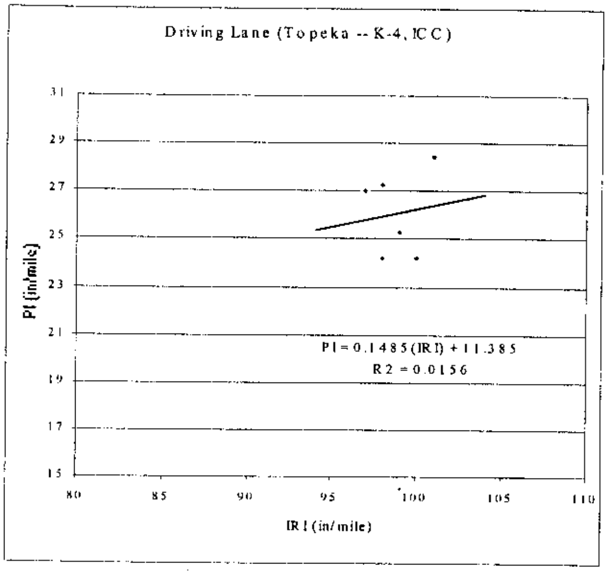
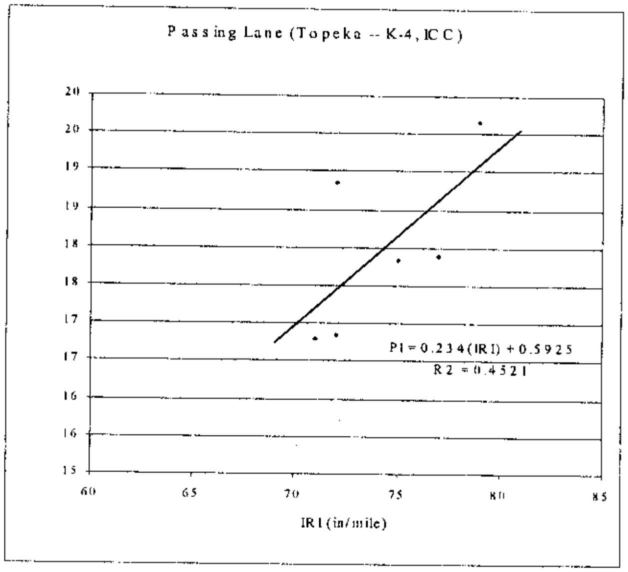
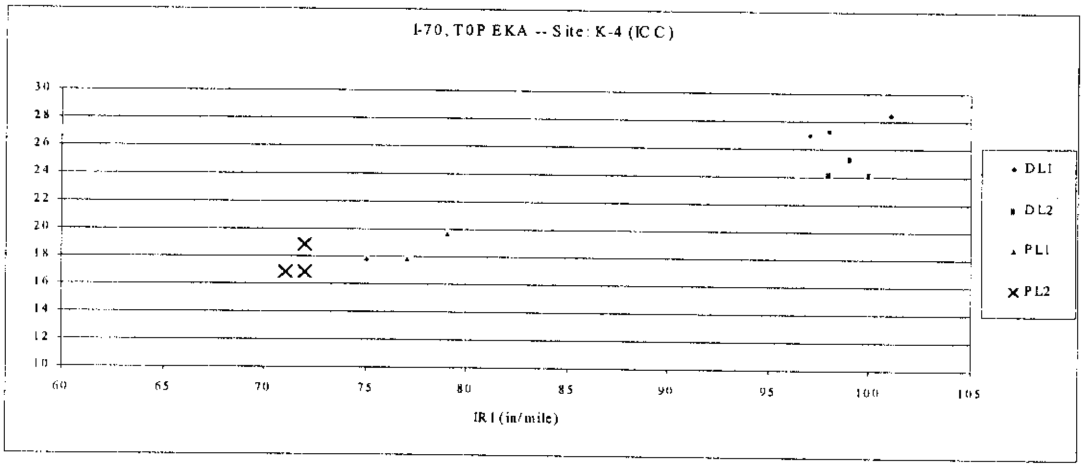
Appendix A: Graphical Relationships

Figure A.1: Correlation between PI and IRI for K-4 Site of Topeka Section for ICC ATV







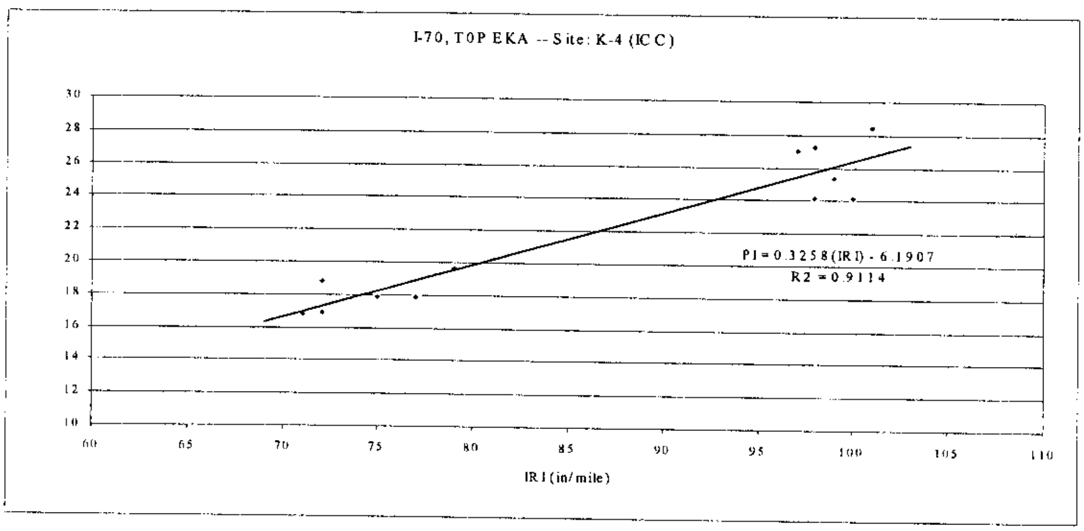
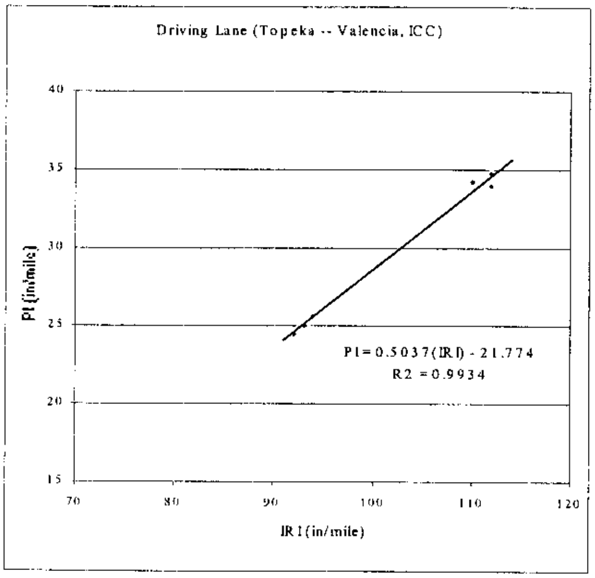
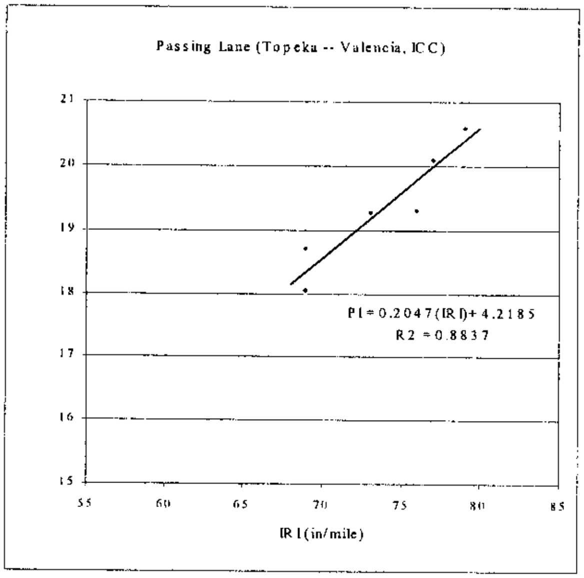
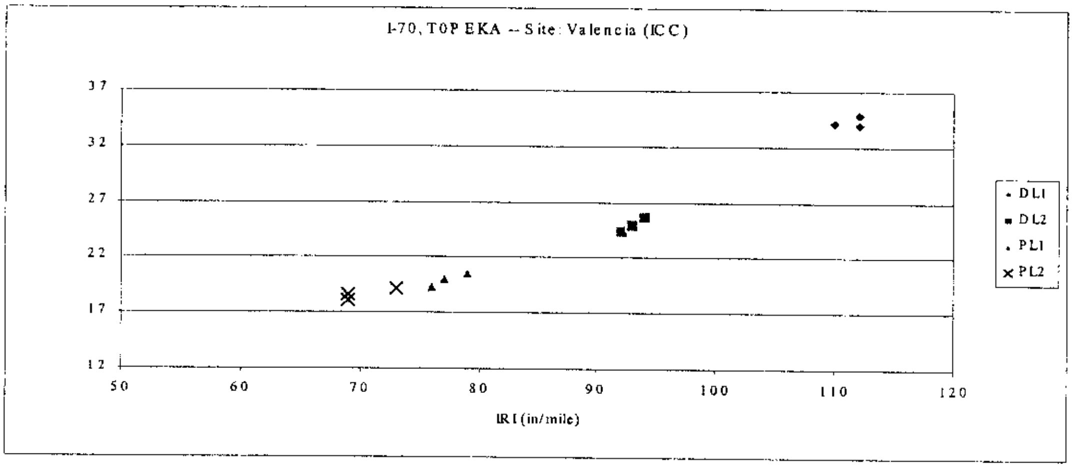


Figure A.2: Correlation between PI and IRI for Valencia Site of Topeka Section for ICC ATV







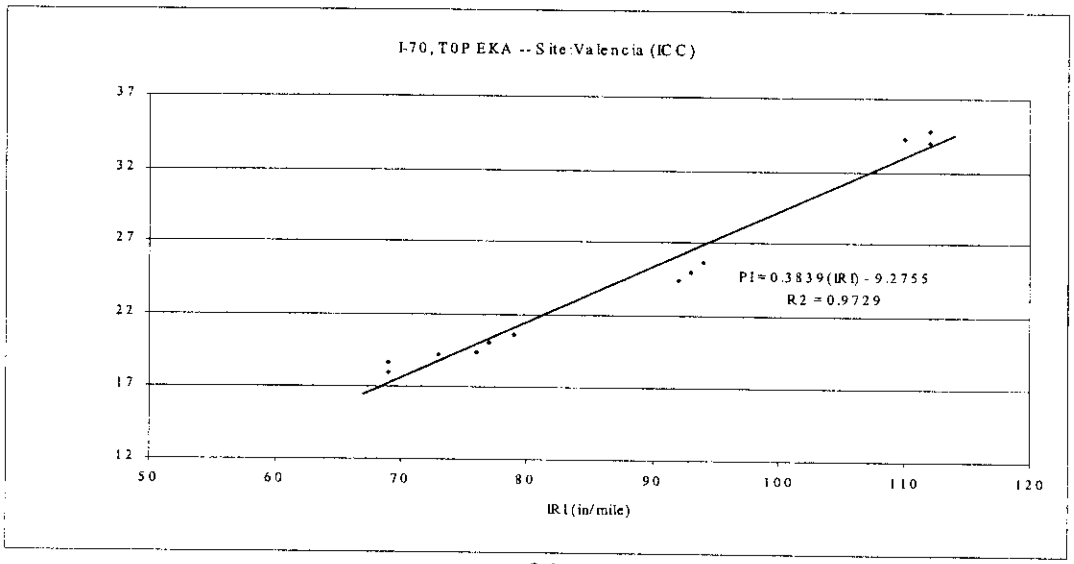
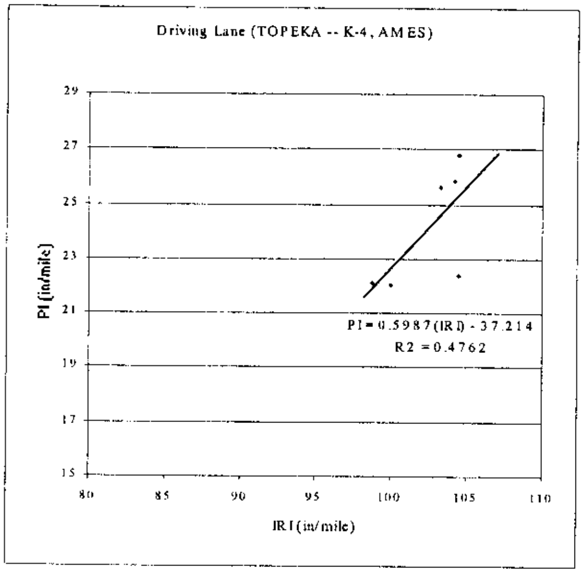
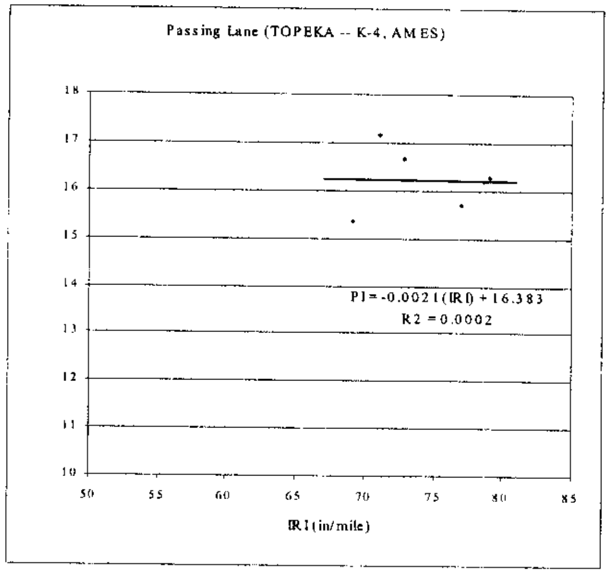
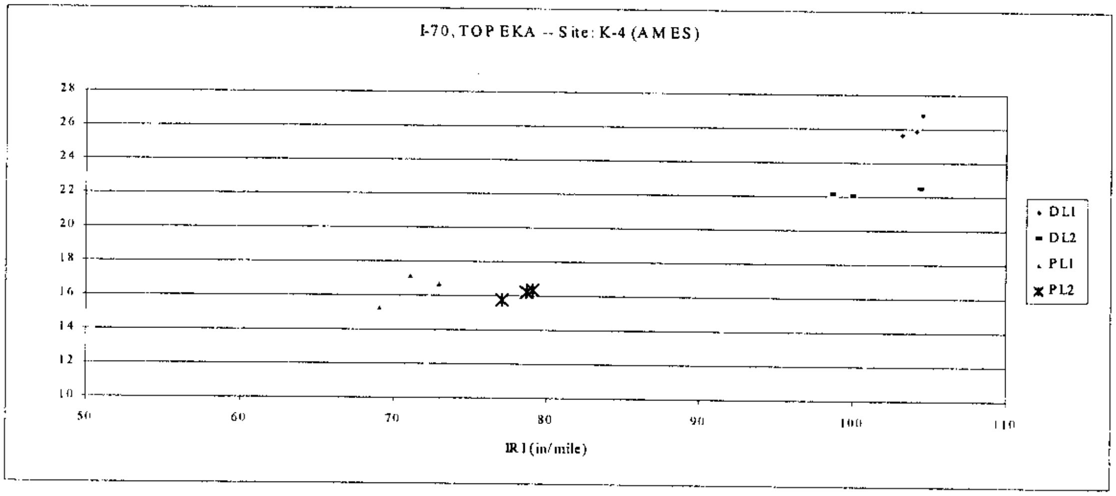


Figure A.3: Correlation between PI and IRI for K-4 Site of Topeka Section for AMES LISA







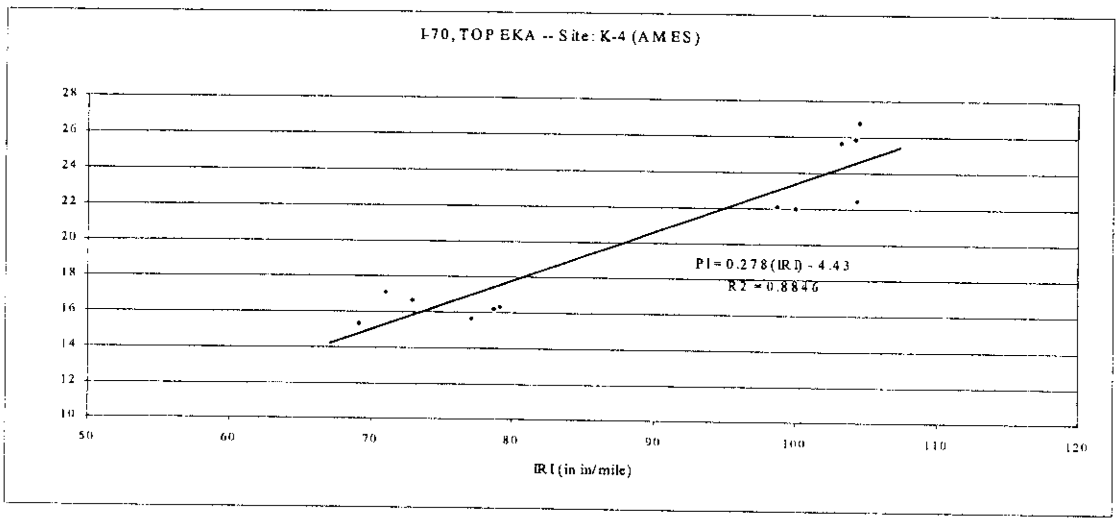
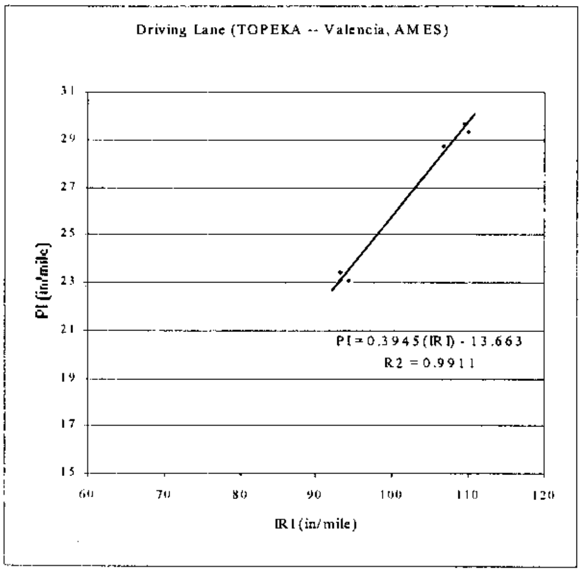
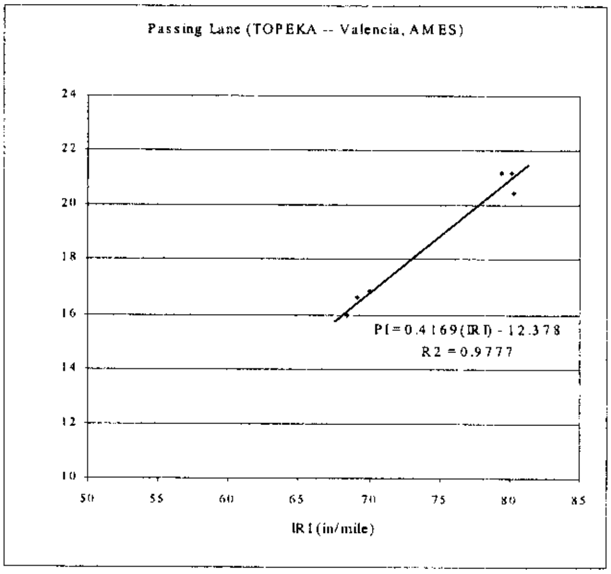
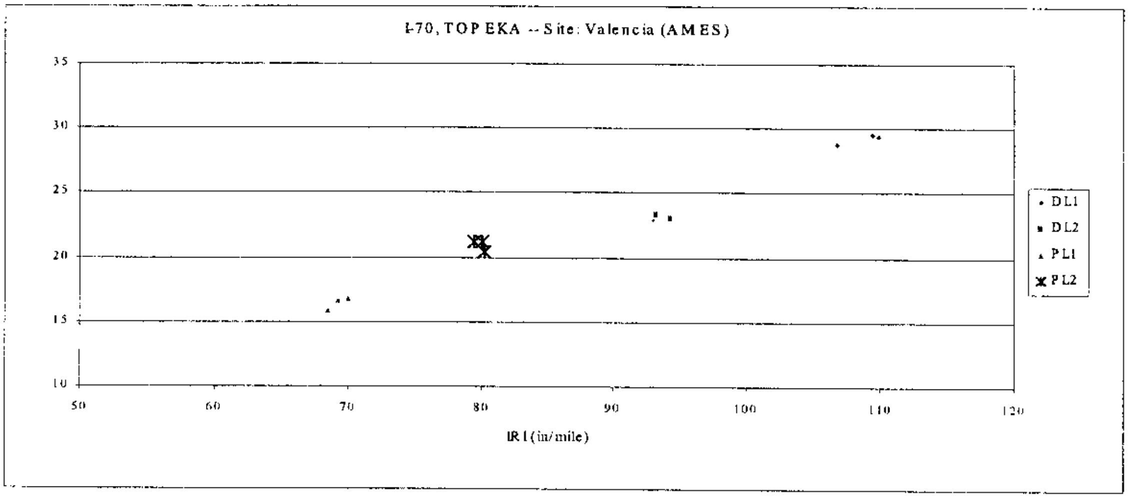


Figure A.4: Correlation between PI and IRI for Valencia Site of Topeka Section for AMES LISA







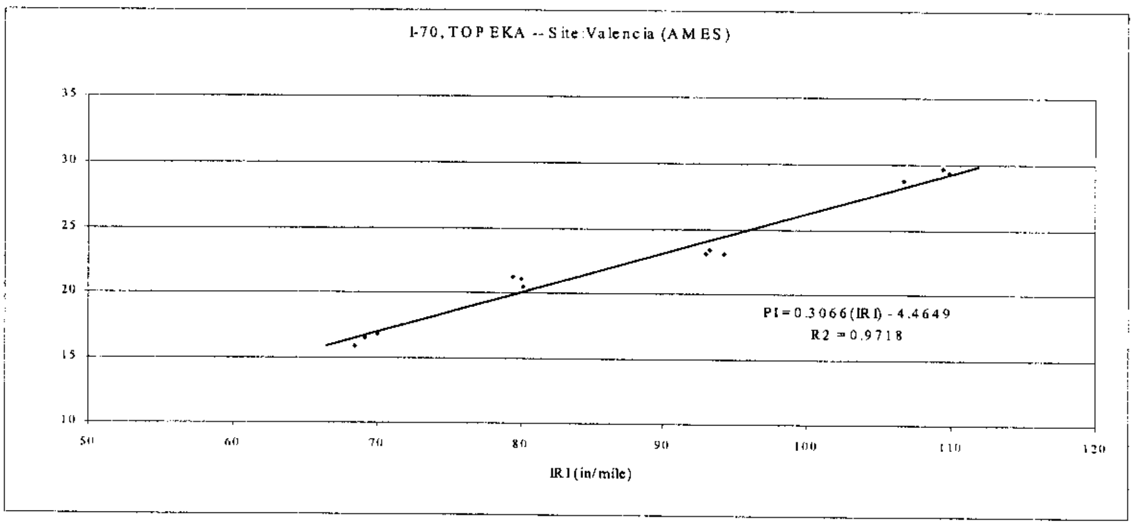
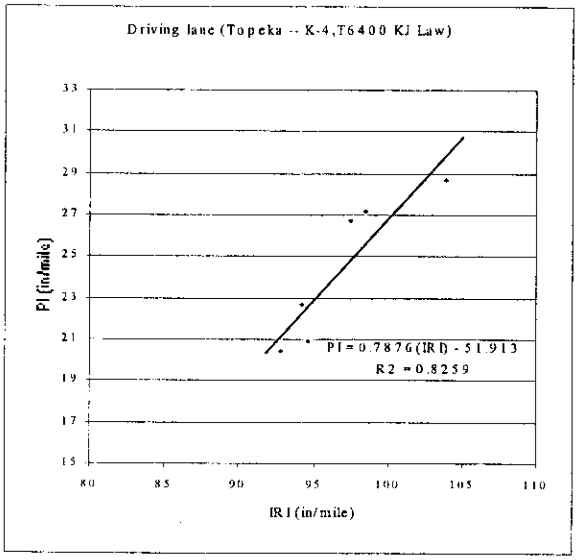
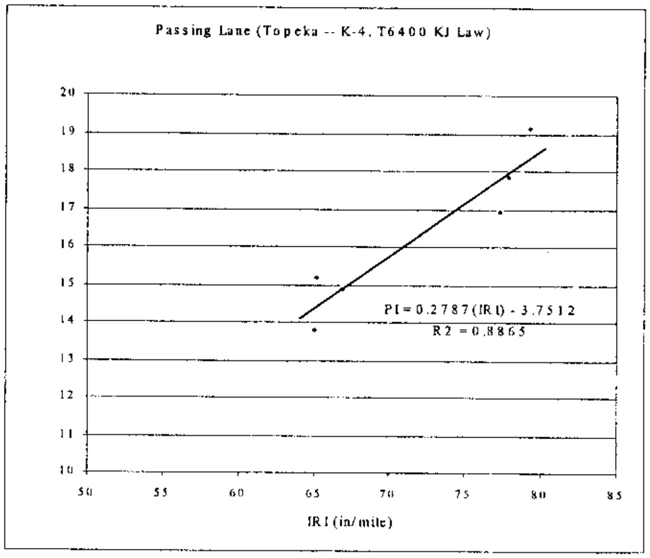
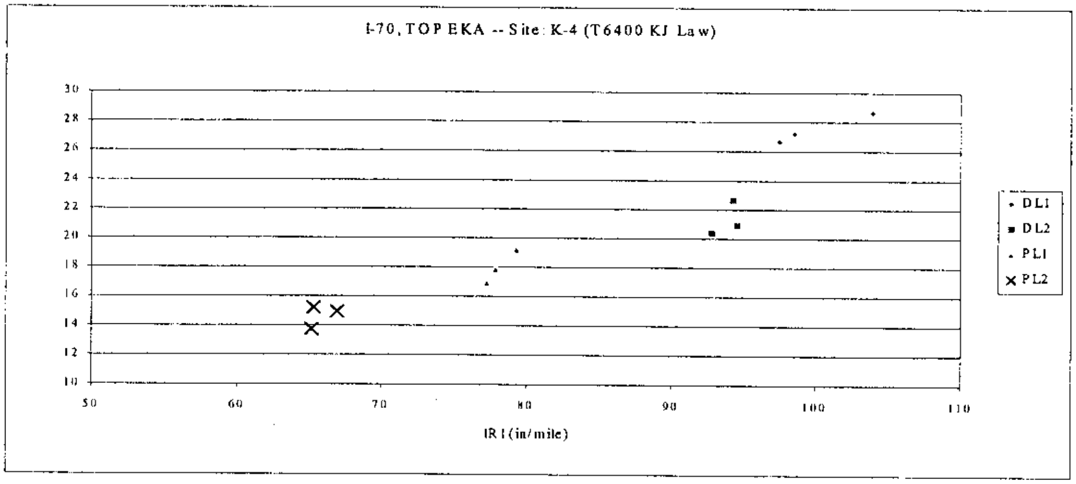


Figure A.5: Correlation between PI and IRI for Site K-4 of Topeka Section for T6400 K.J. Law







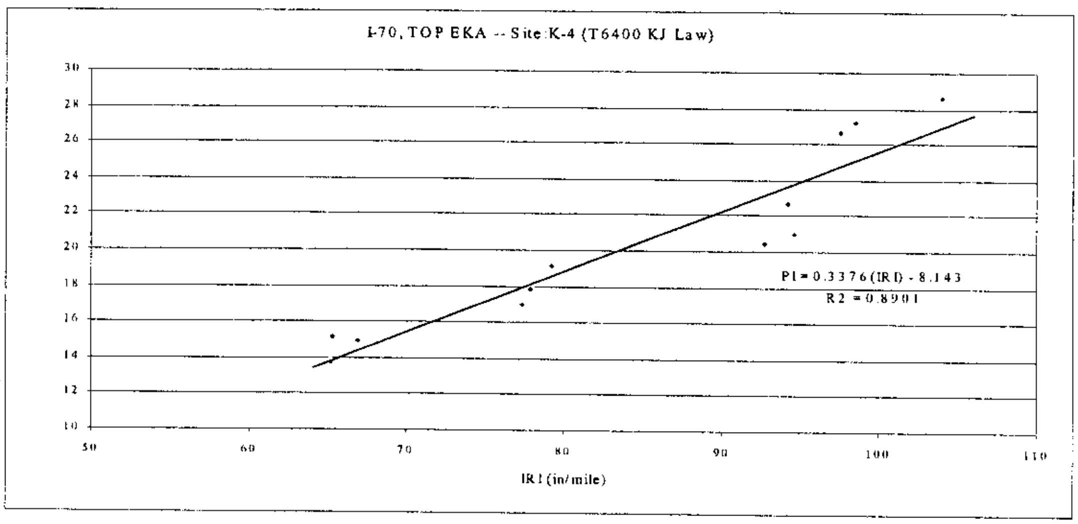
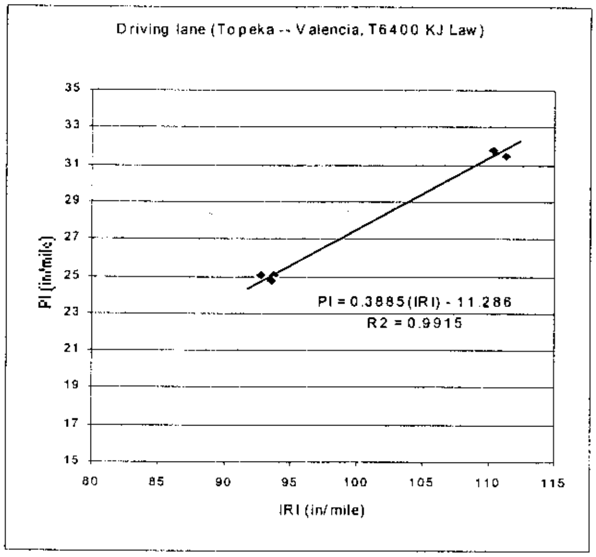
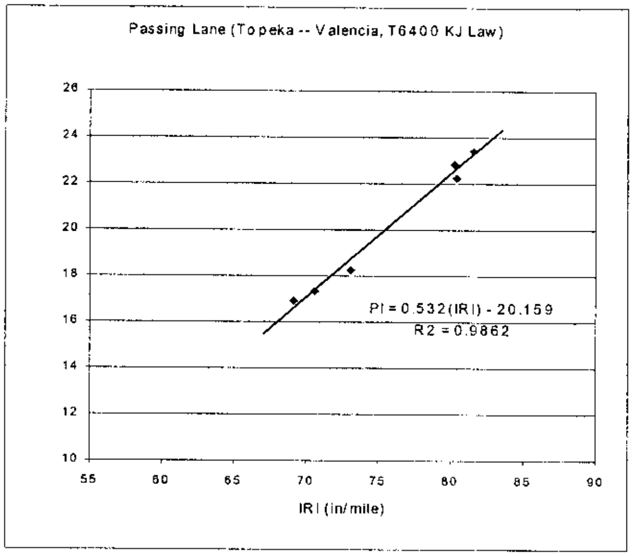
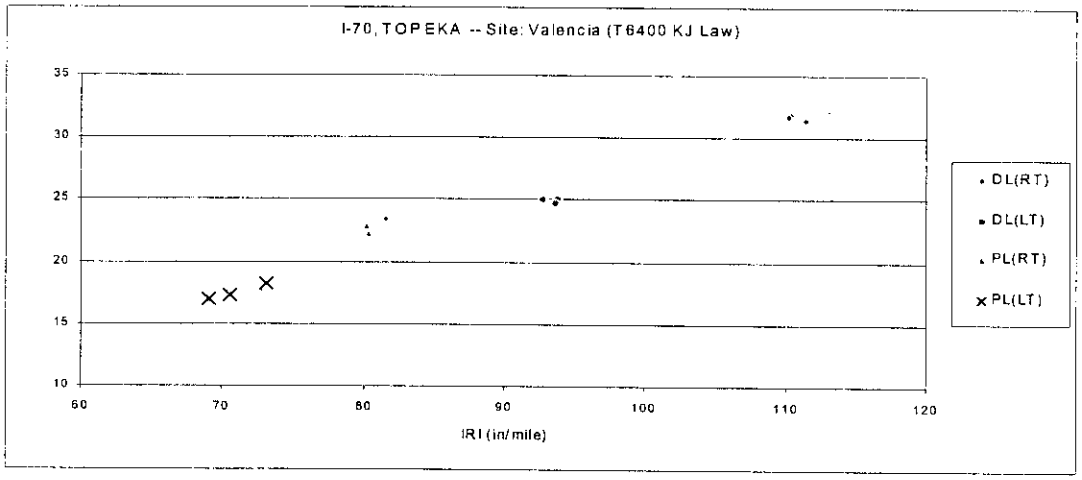


Figure A.6: Correlation between PI and IRI for Site Valencia of Topeka Section for T6400 K.J.Law







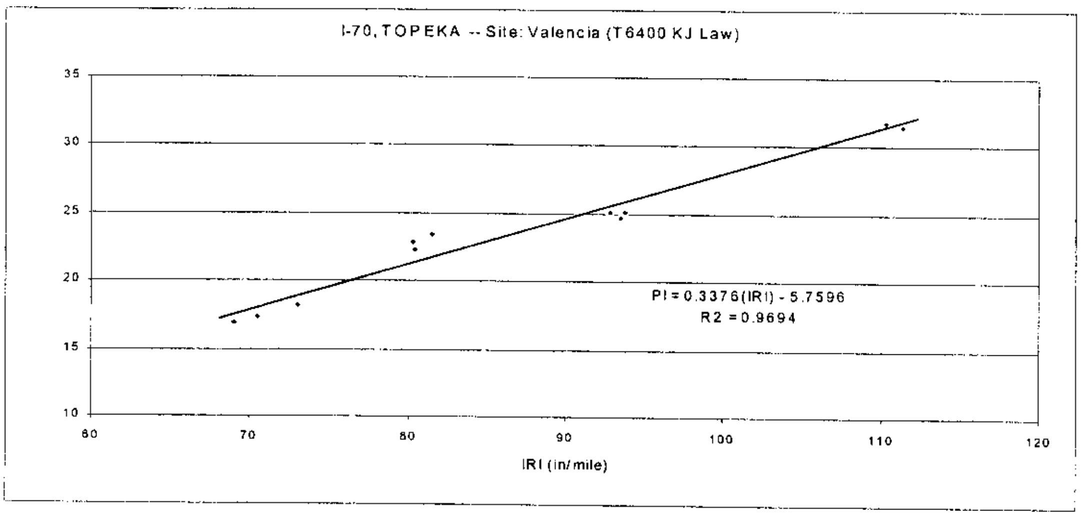
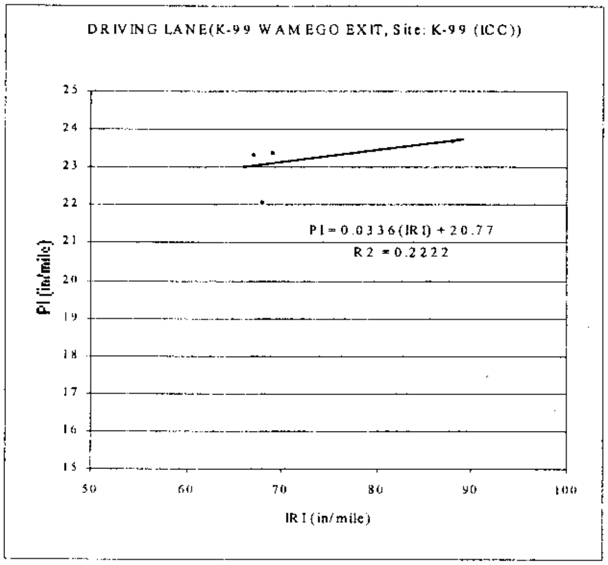
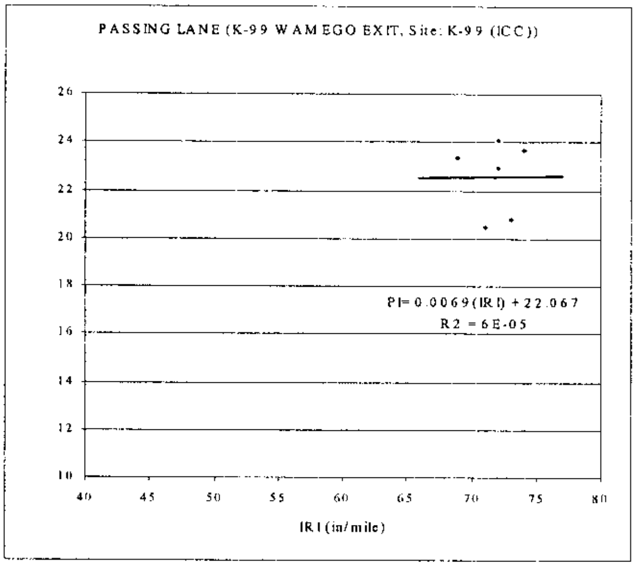
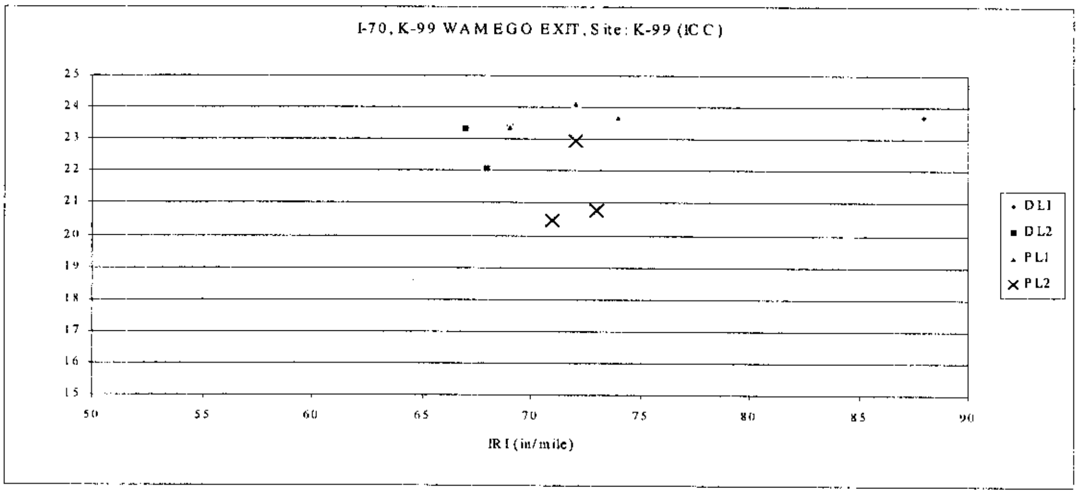


Figure A.7: Correlation between PI and IRI for K-99 Site of Wamego Exit Section for ICC ATV







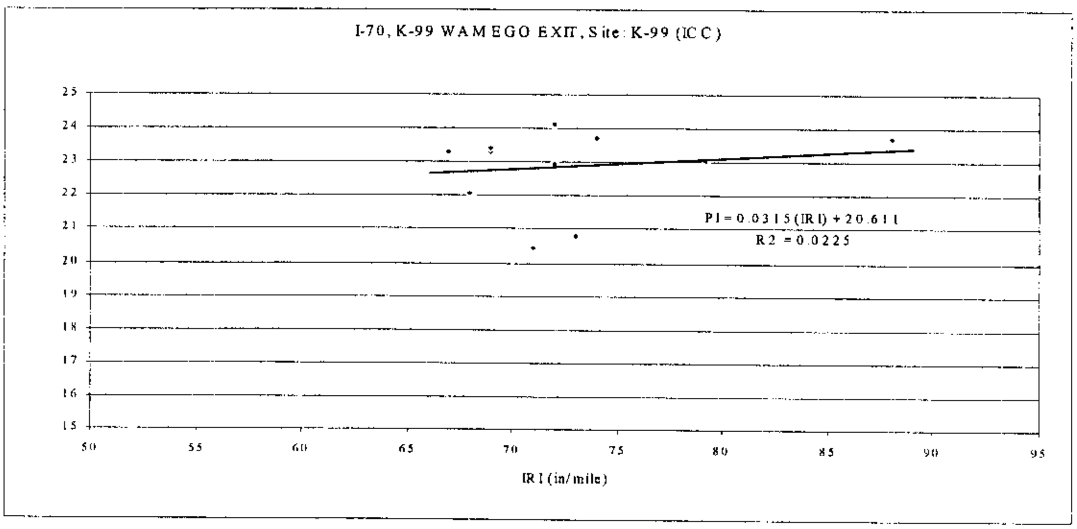
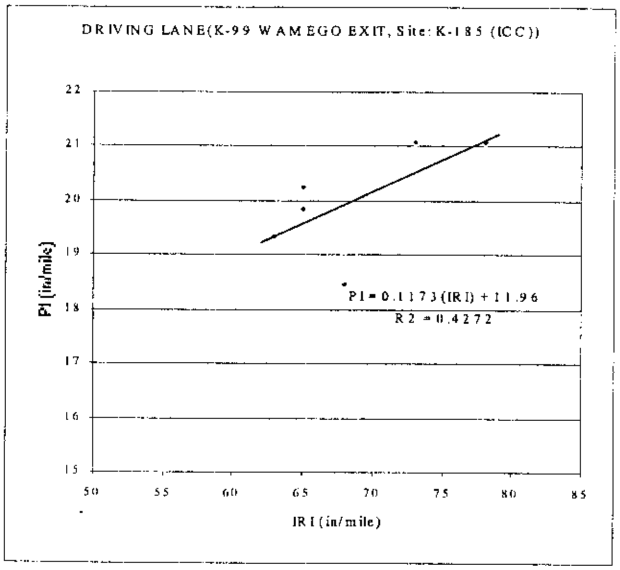
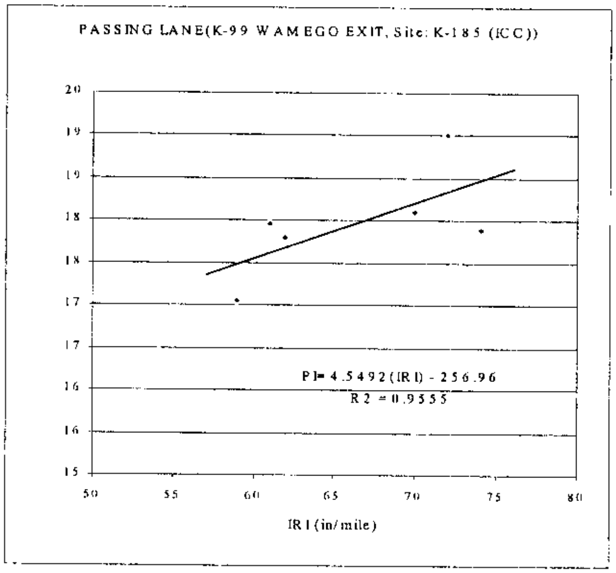
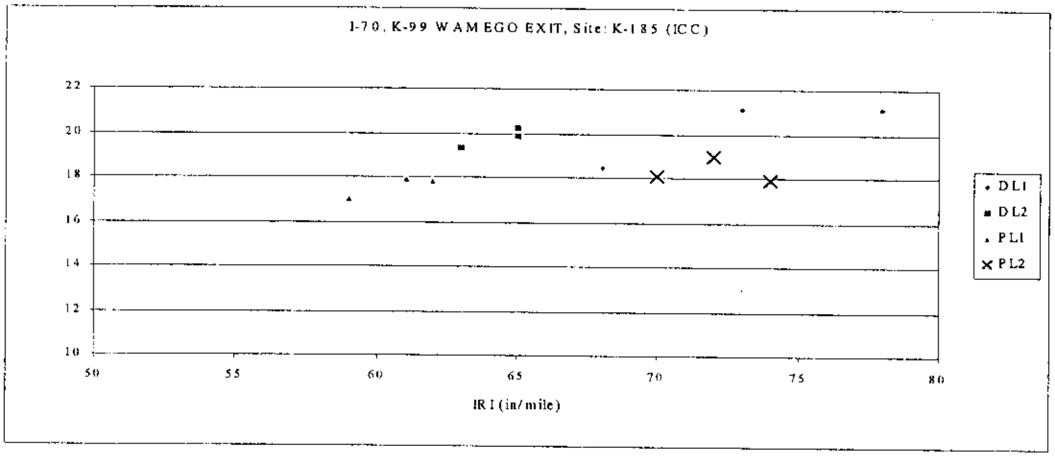


Figure A.8:Correlation between PI and IRI for K-185 Site of Wamego Exit Section for ICC ATV







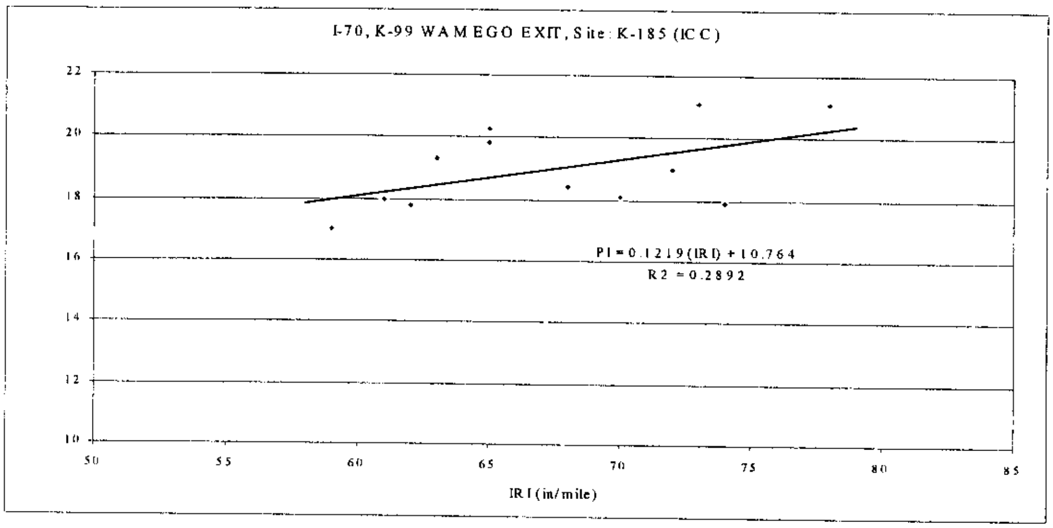
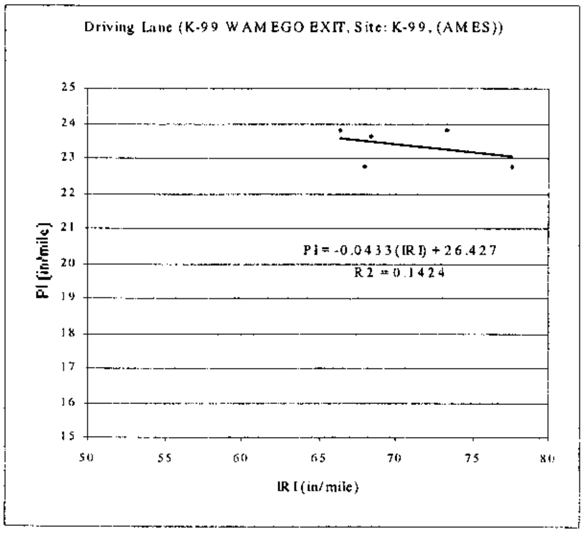
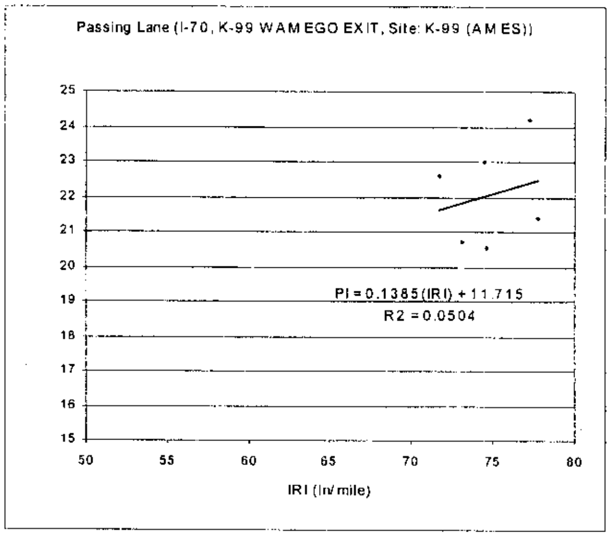
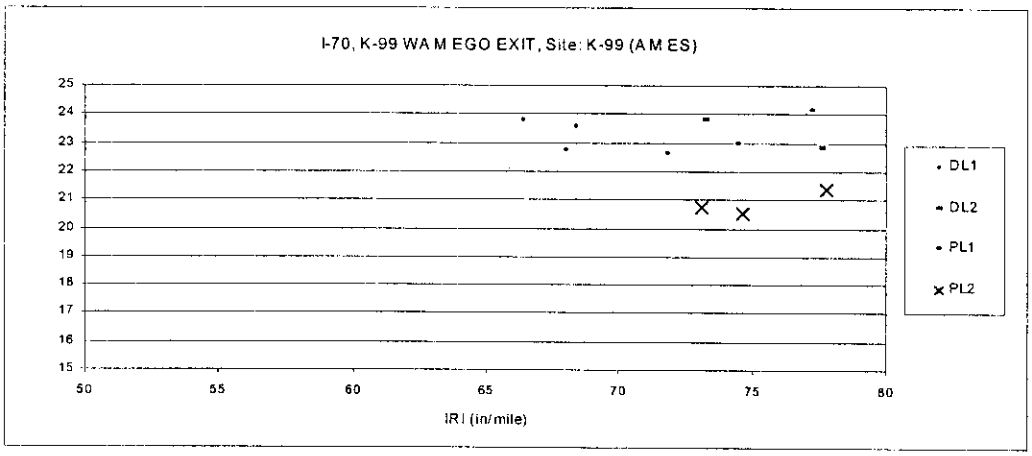


Figure A.9: Correlation between PI and IRI for K-99 Site of Wamego Exit Section for AMES LISA







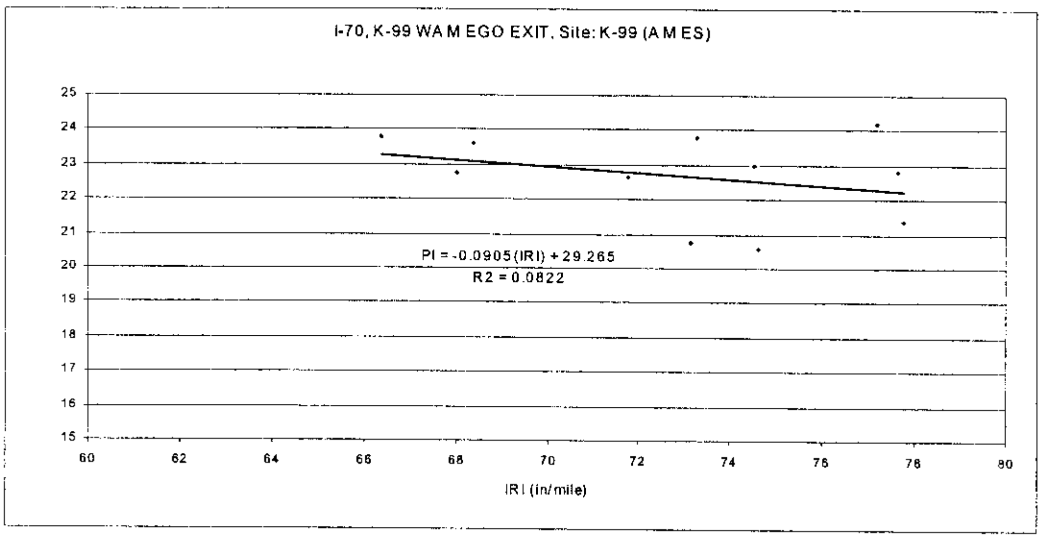


Figure A.10: Correlation between PI and IRI for K-185 Site of Wamego Exit Section for AMES LISA

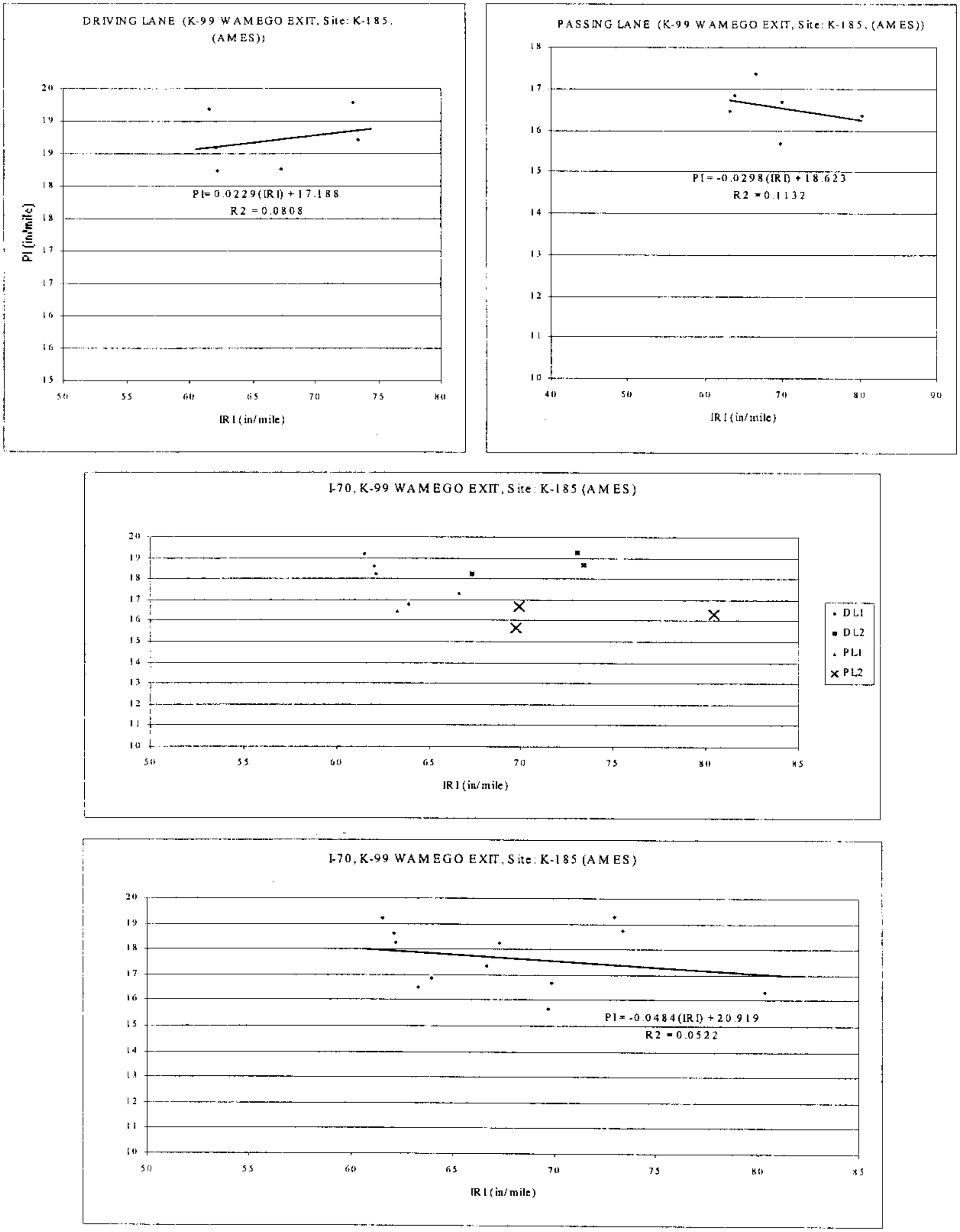
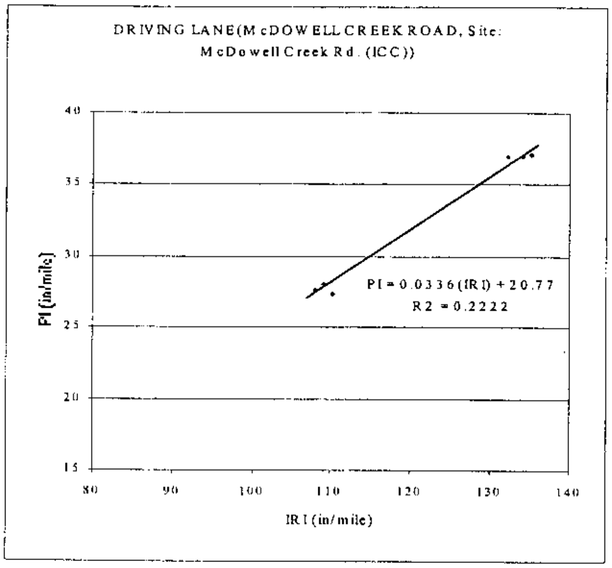
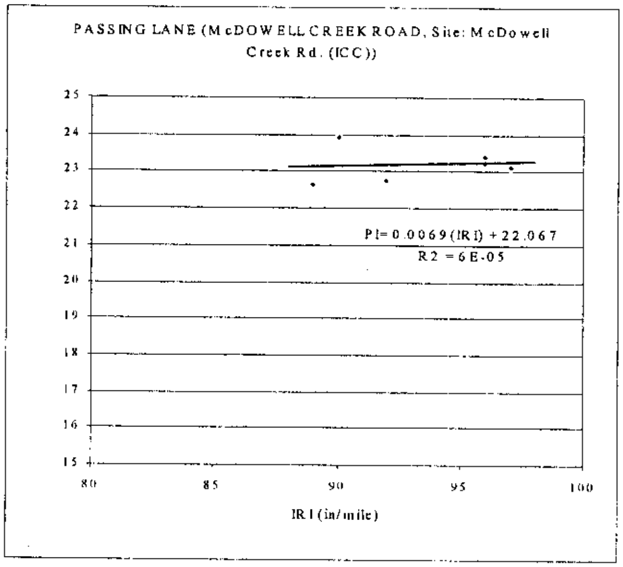
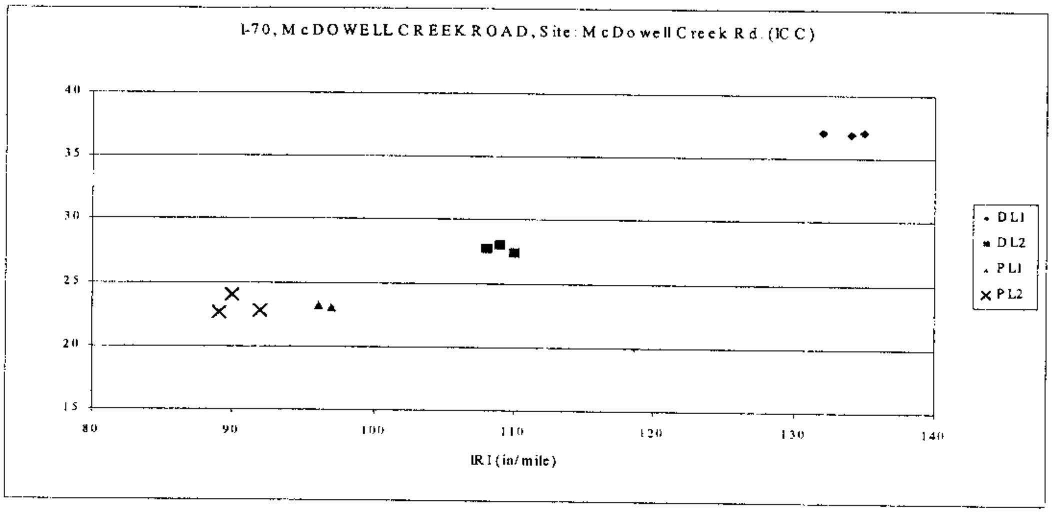


Figure A.11: Correlation between PI and IRI for McDowell Creek Road Site of McDowell Creek Road Section for ICC ATV







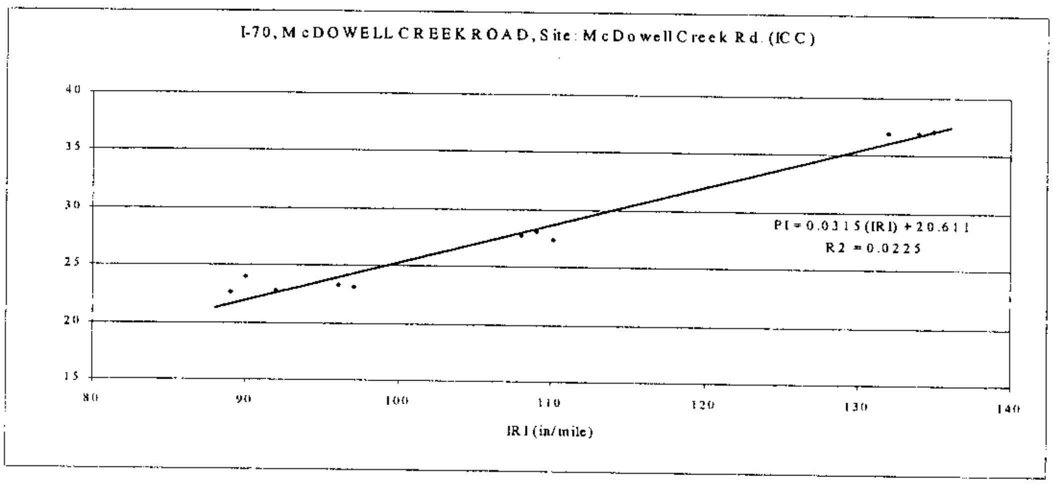
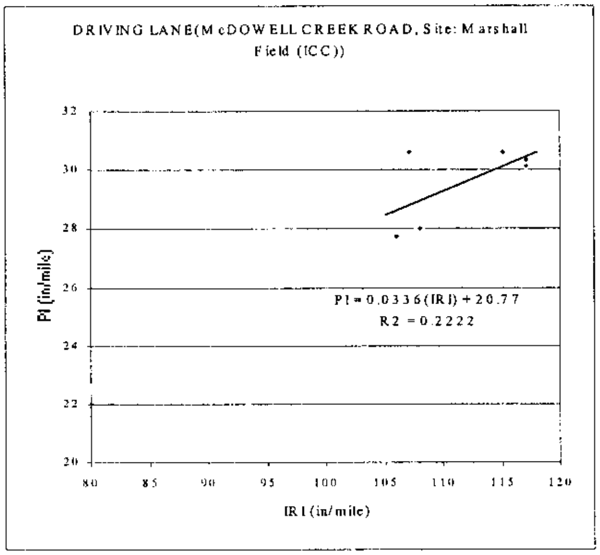
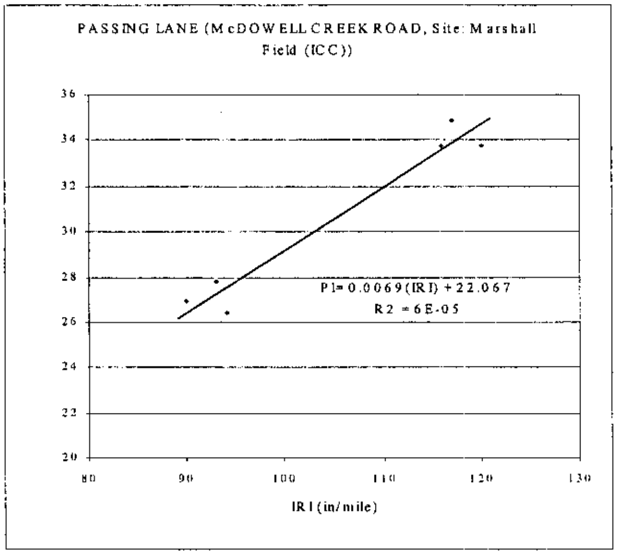
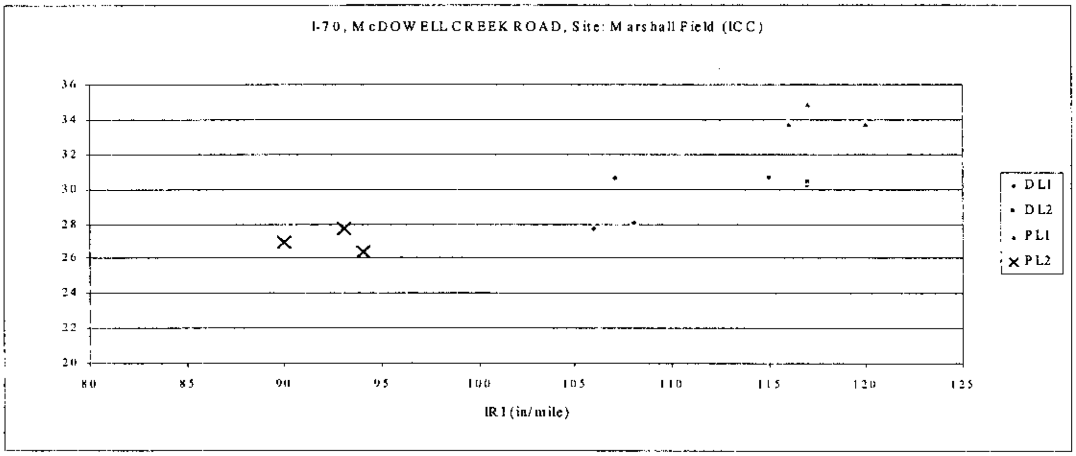


Figure A.12: Correlation between PI and IRI for Marshall Field Site of McDowell Creek Road Section for ICC ATV







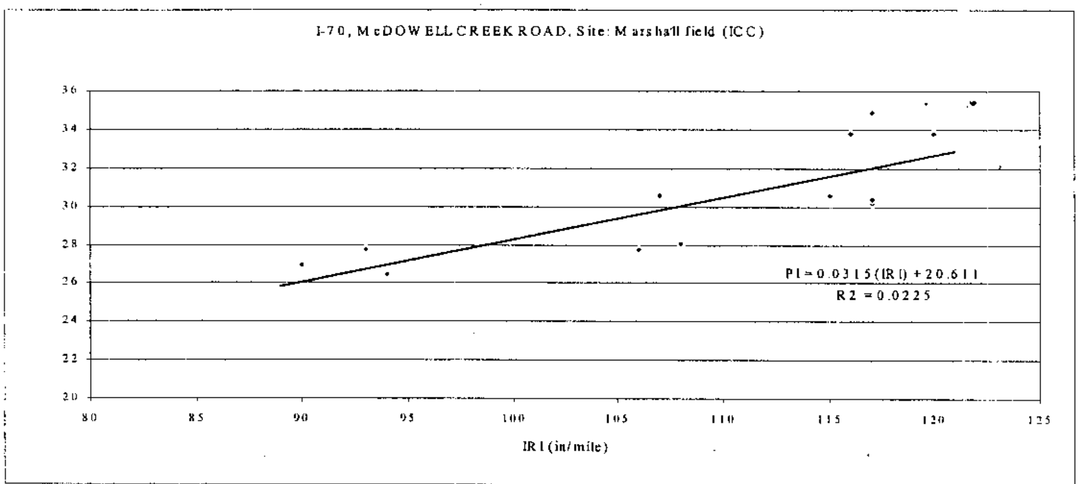
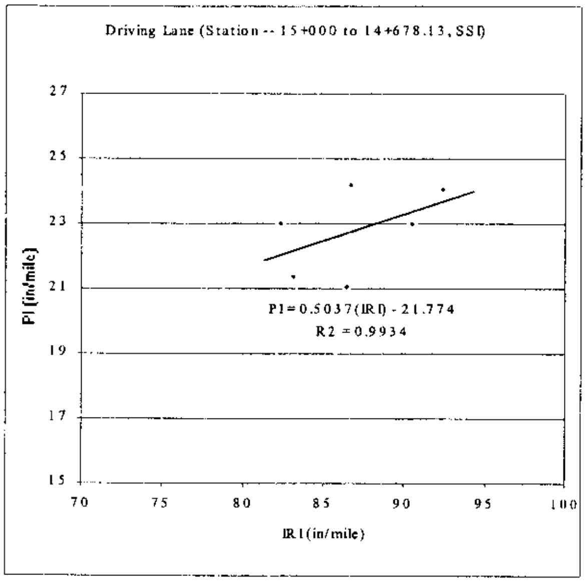
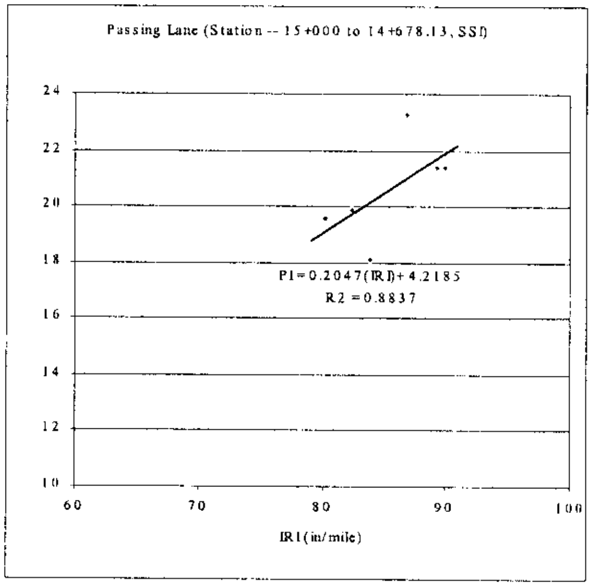
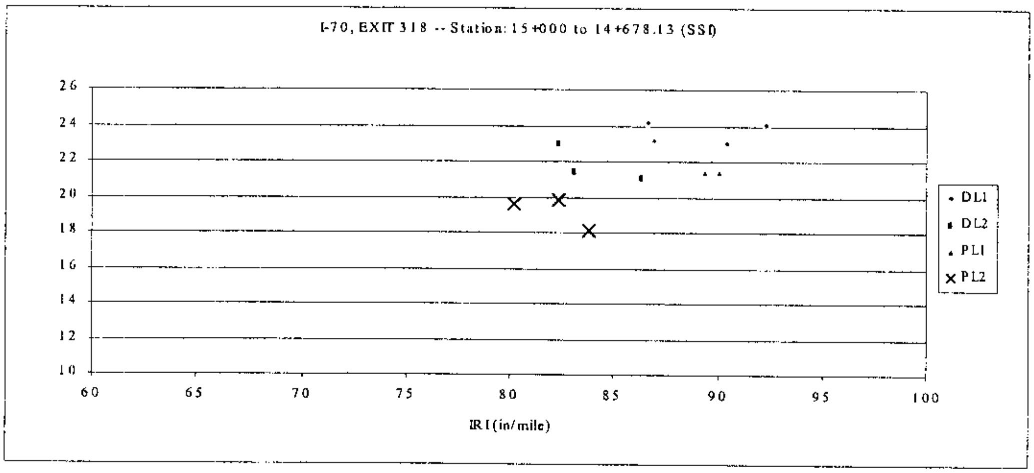


Figure A.13: Correlation between PI and IRI for East Site of Exit 318 Section for SSI







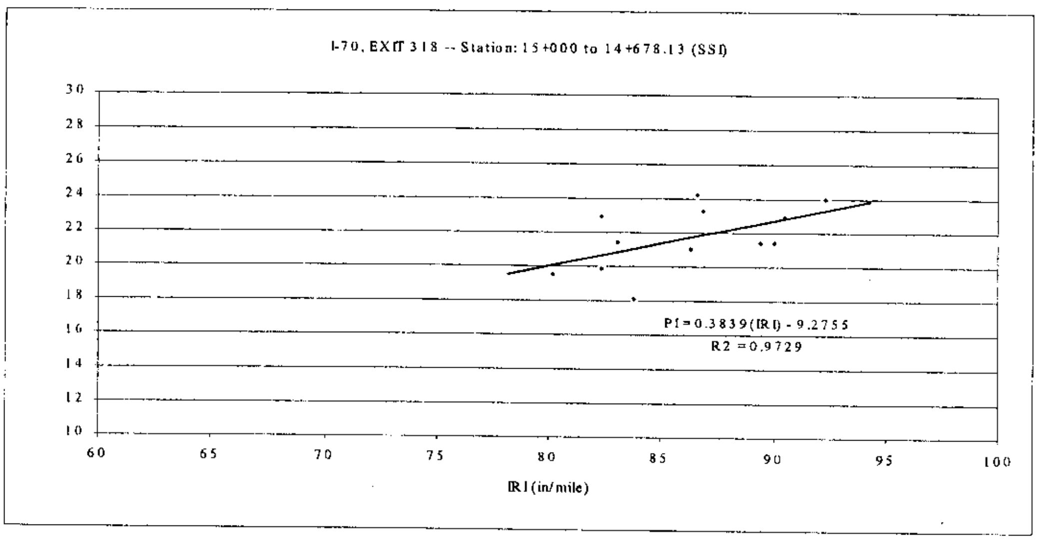
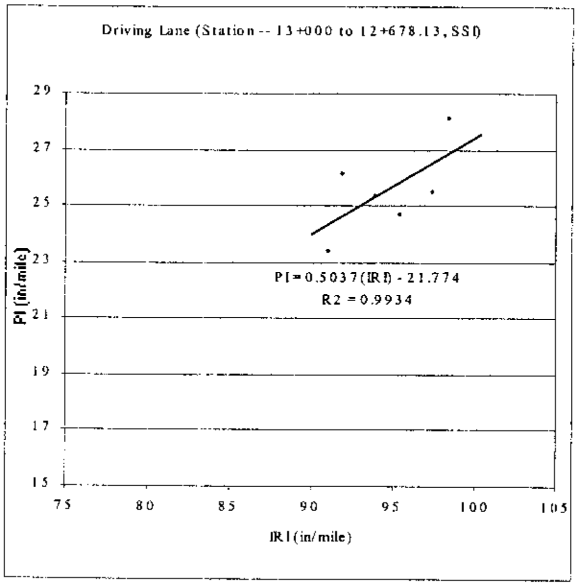
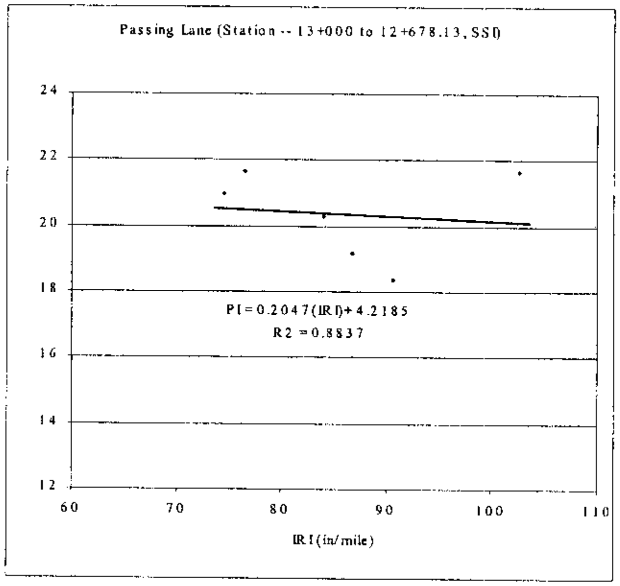
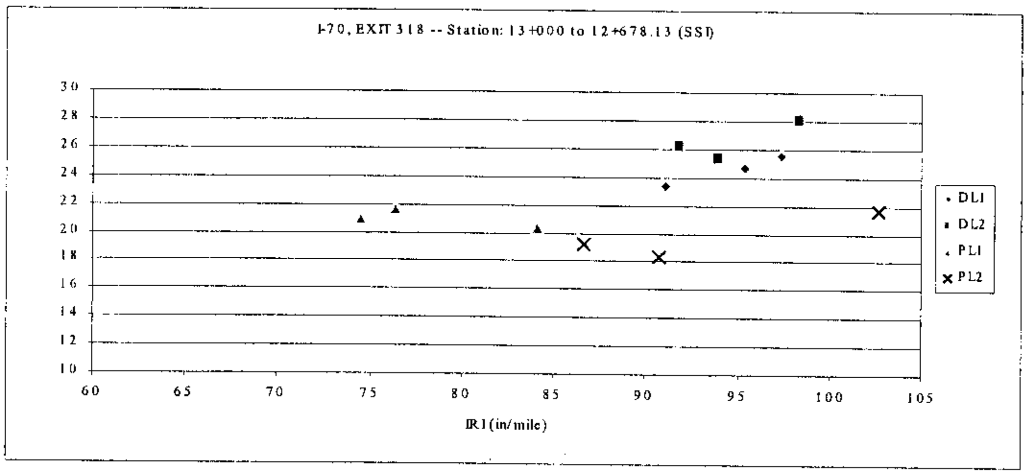


Figure A.14: Correlation between PI and IRI for West Site of Exit 318 Section for SSI







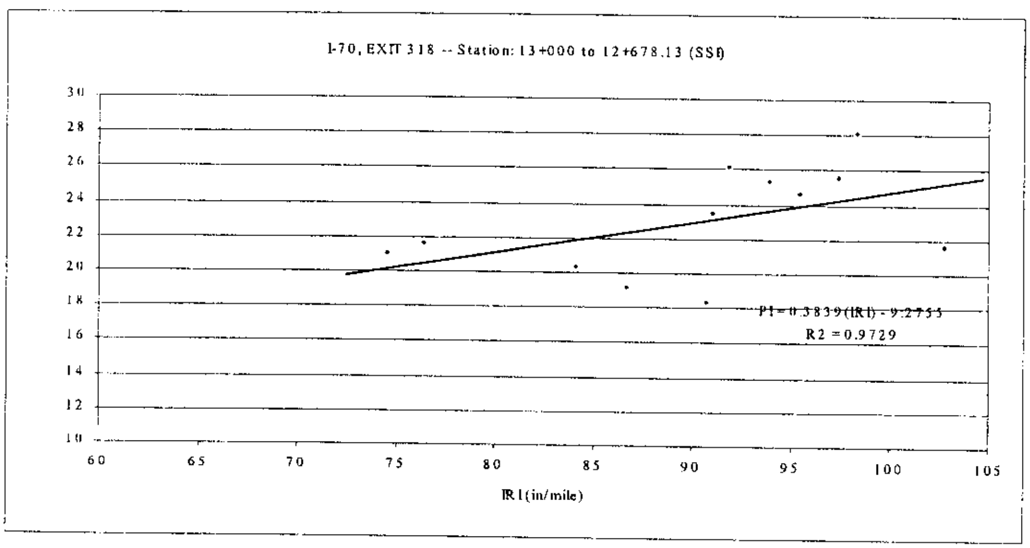


Figure A.15: Comparison between ICC and KDOT California-Type Profilograph (Marshall Field)

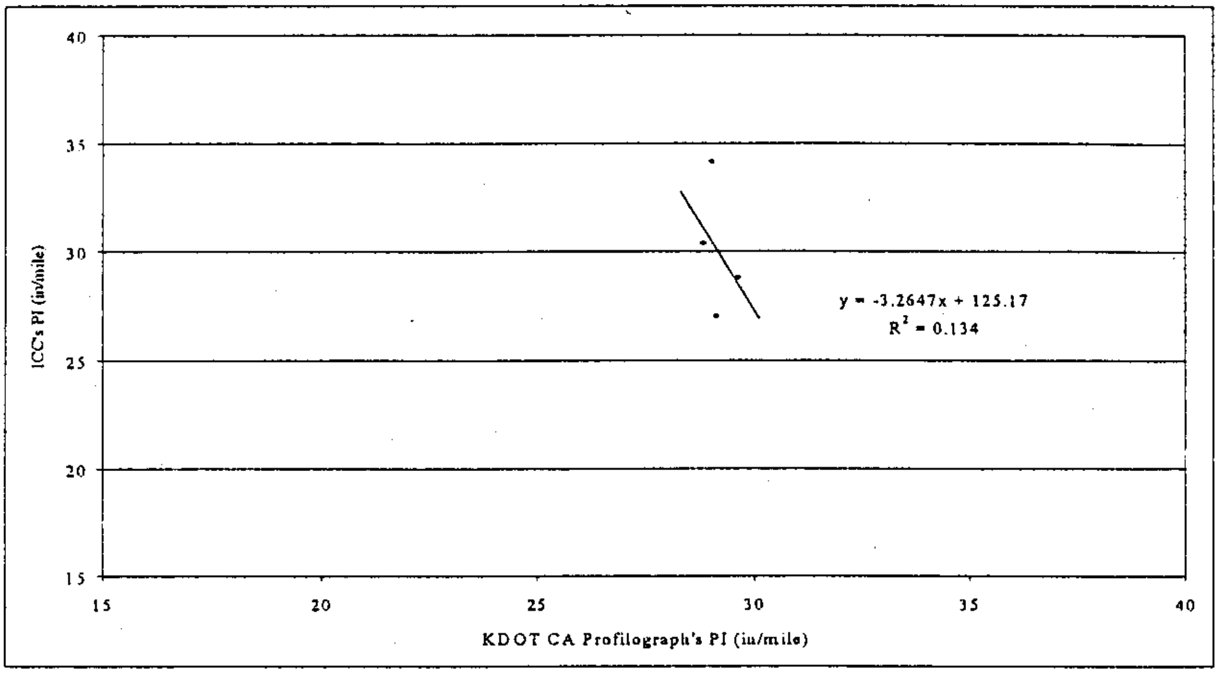


Figure A.16: Comparison between ICC and KDOT California-Type Profilograph (McDowell Creek Road)

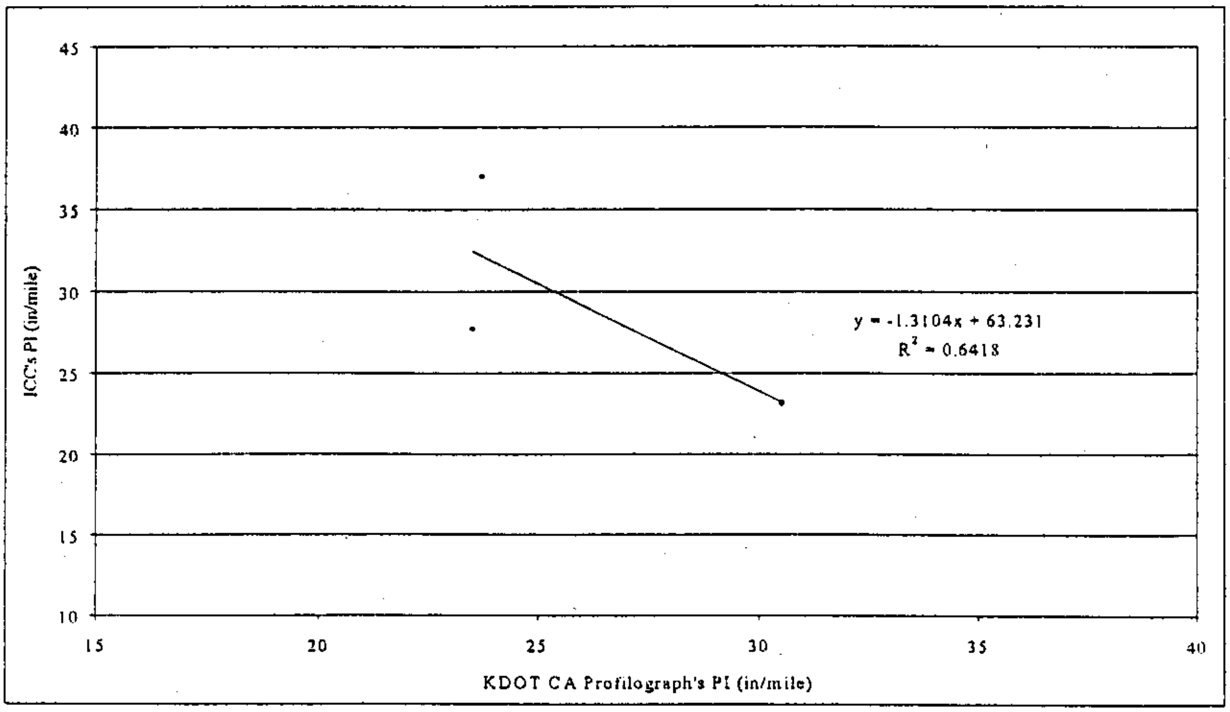


Figure A.17: Comparison between ICC and KDOT California-Type Profilograph
(Wamego Exit, K-99)

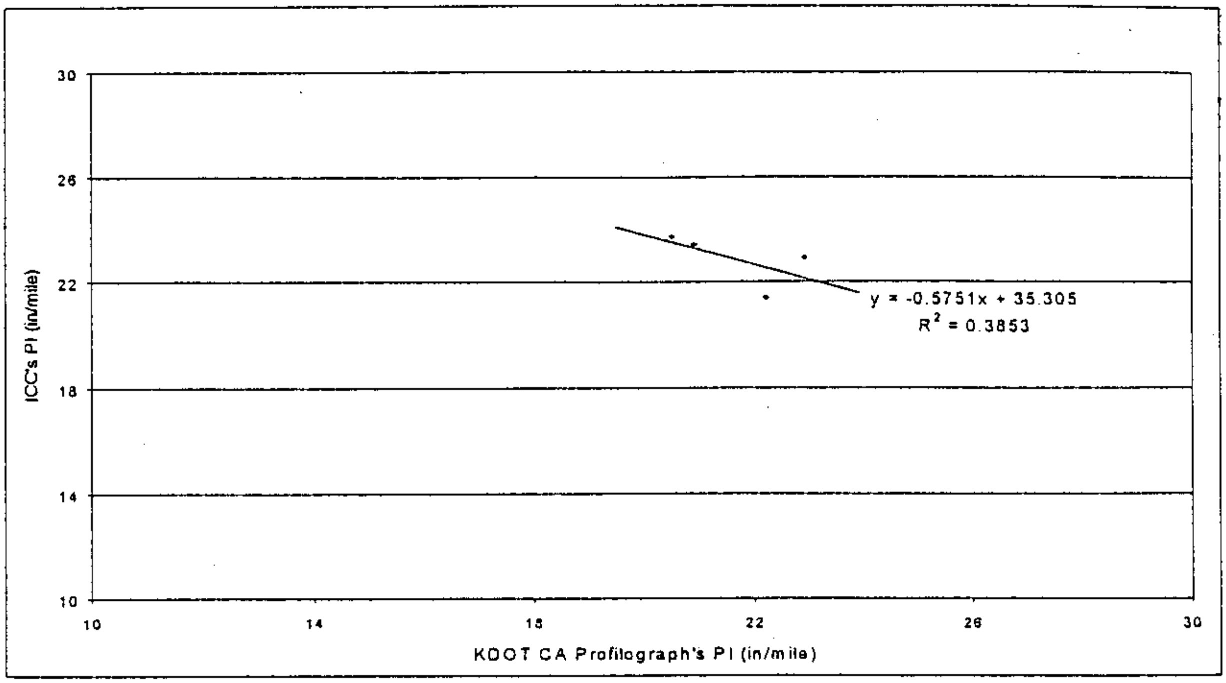


Figure A.18: Comparison between LISA and KDOT California-Type Profilograph
(Wamego Exit, K-99)

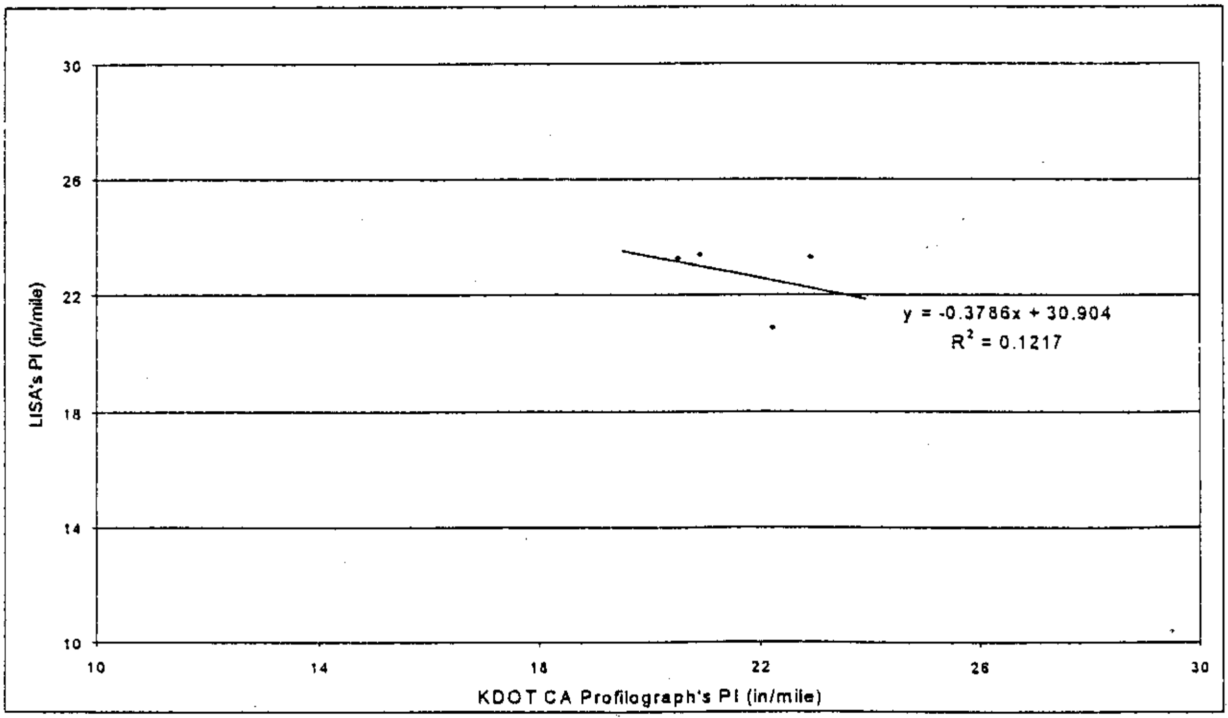


Figure A.19: Comparison between ICC and KDOT California-Type Profilograph (Wamego Exit, K-185)

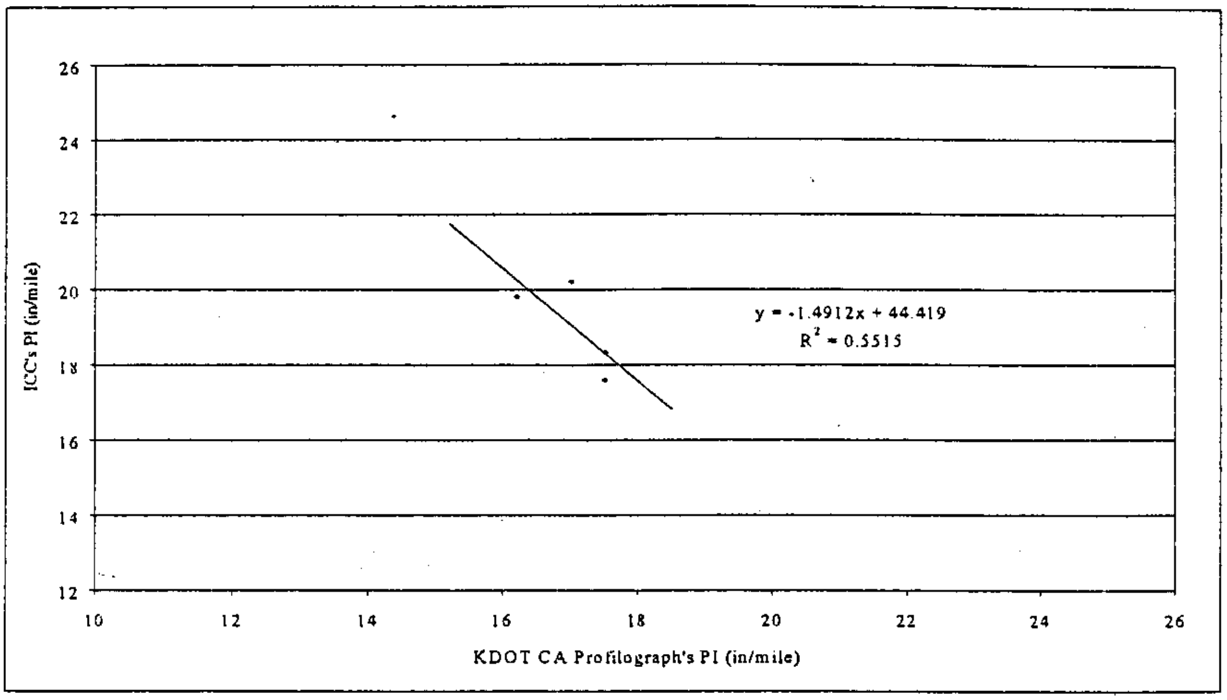


Figure A.20: Comparison between LISA and KDOT California-Type Profilograph (Wamego Exit, K-185)

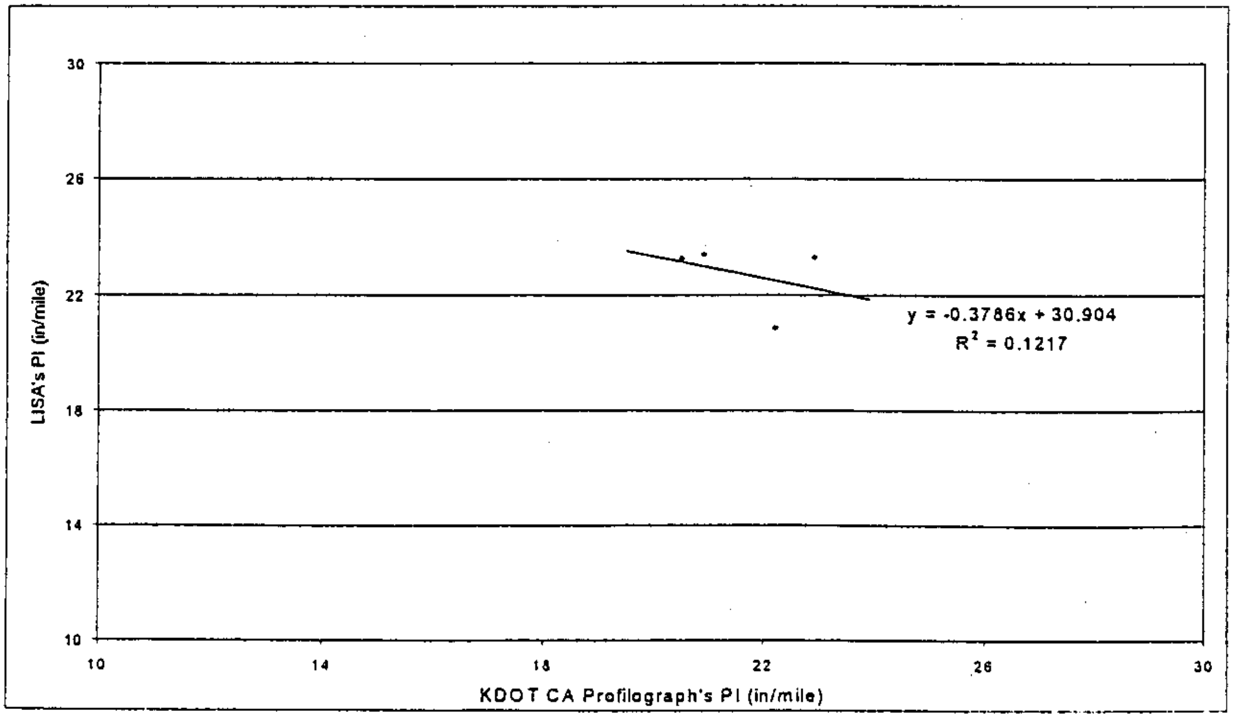


Figure A.21: Comparison between ICC and KDOT California-Type Profilograph
(Topeka, Valencia)

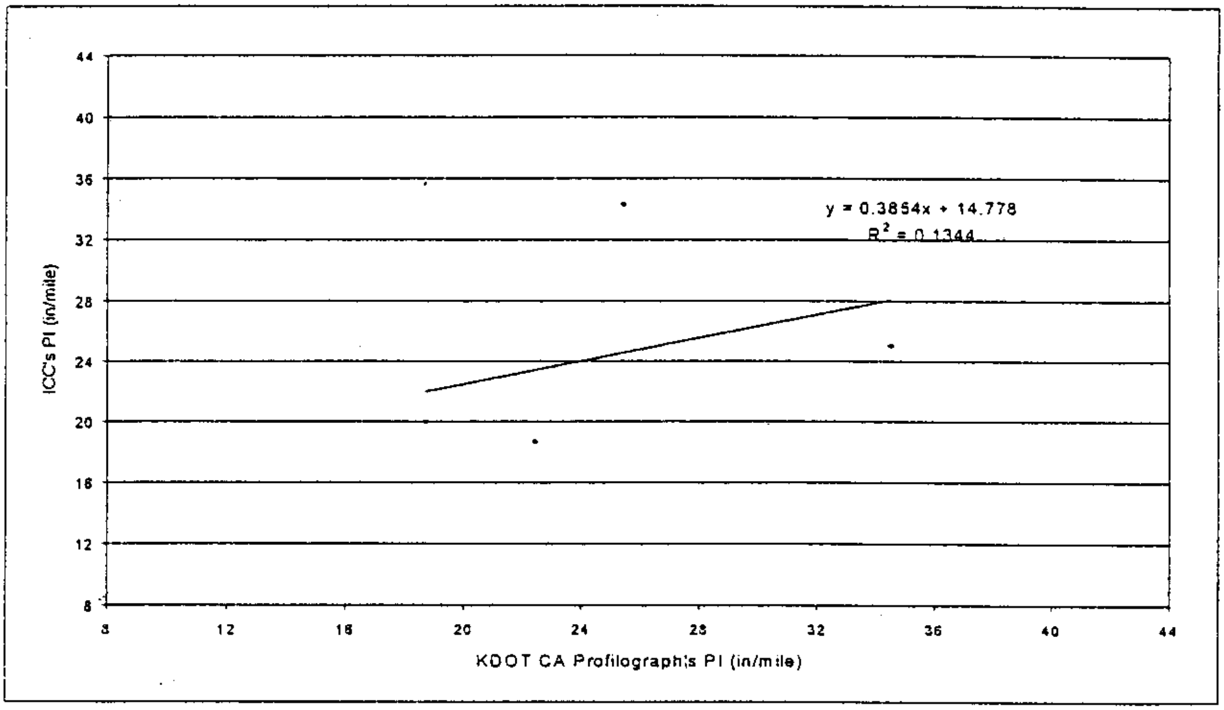


Figure A.22: Comparison between LISA and KDOT California-Type Profilograph
(Topeka, Valencia)

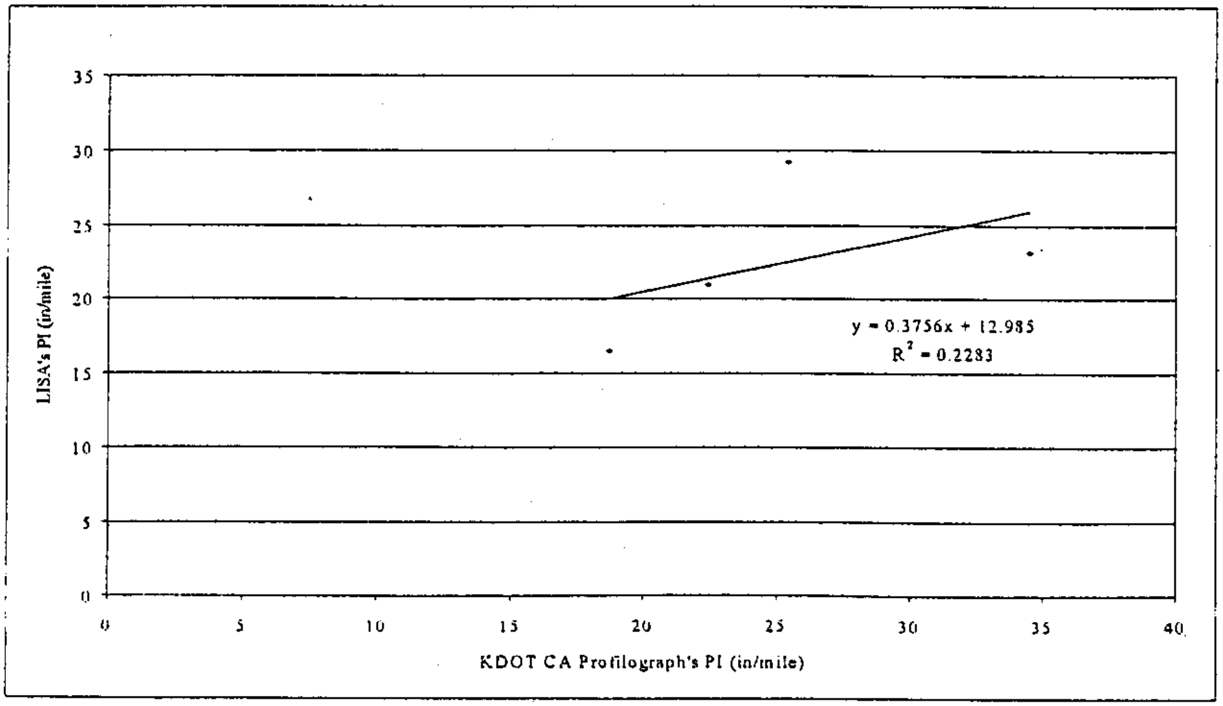


Figure A.23: Comparison between K. J. Law T6400 and KDOT California-Type Profilograph (Topeka, Valencia)

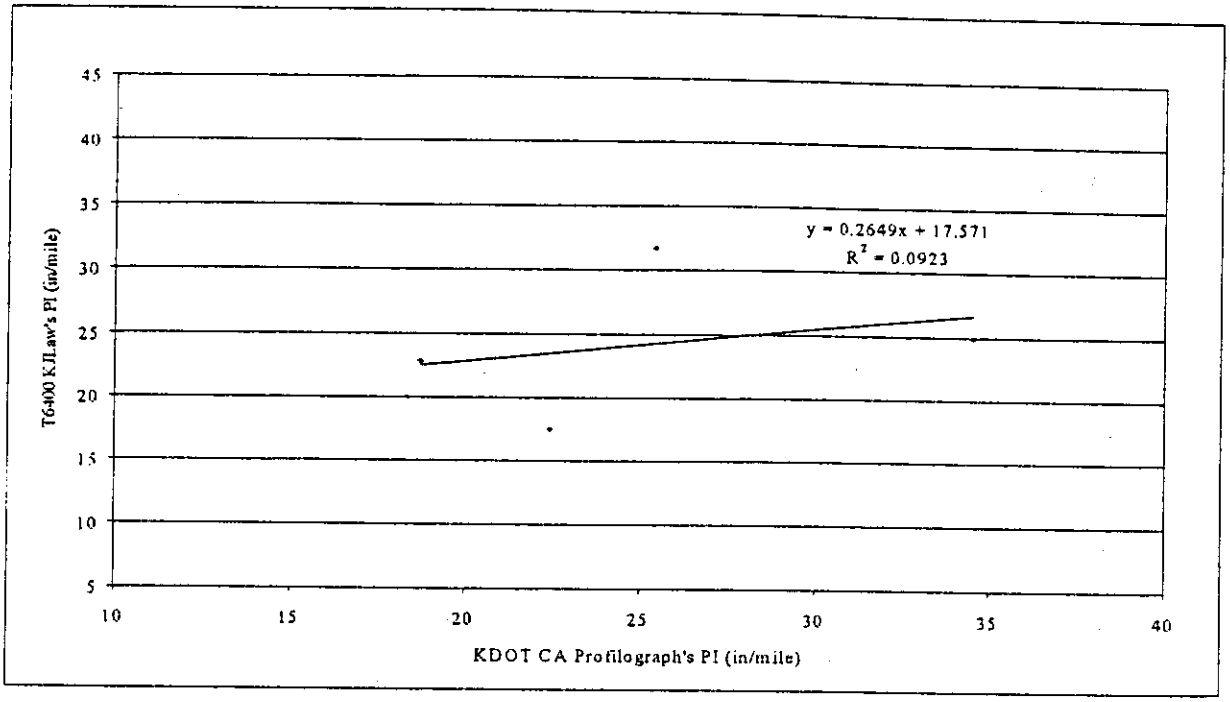


Figure A.24: Comparison between ICC and KDOT California-Type Profilograph (Topeka, K-4)

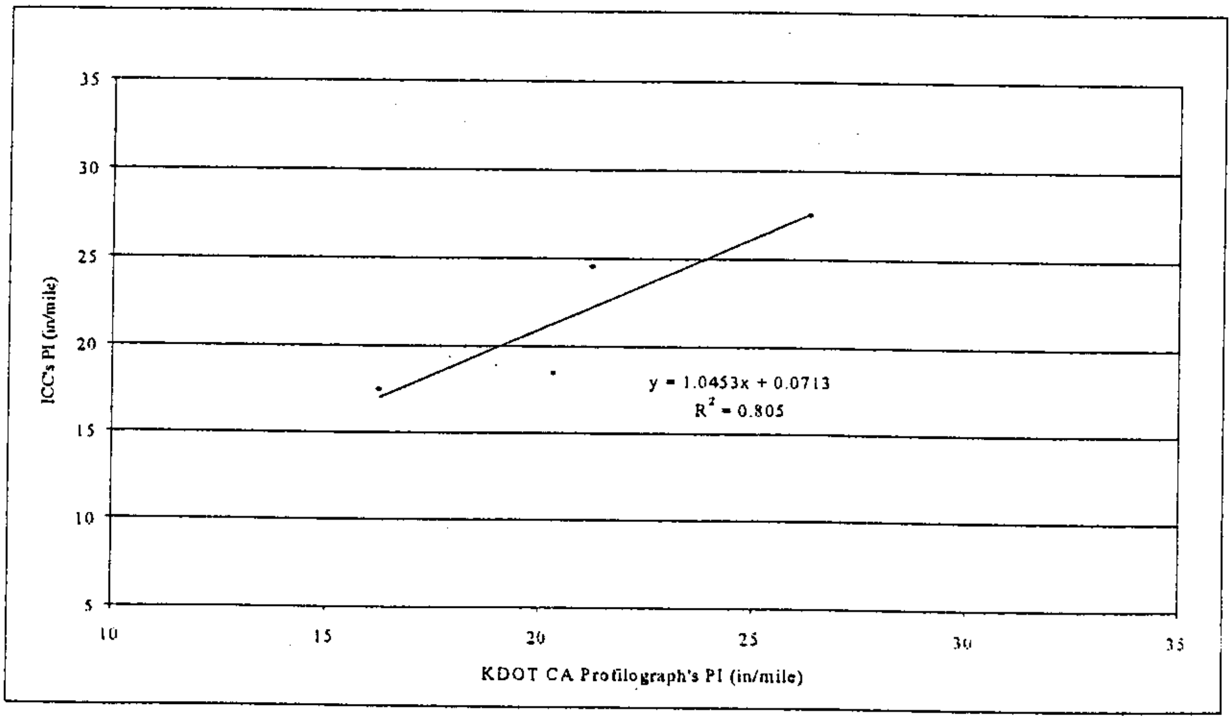


Figure A.25: Comparison between LISA and KDOT California-Type Profilograph (Topeka, K-4)

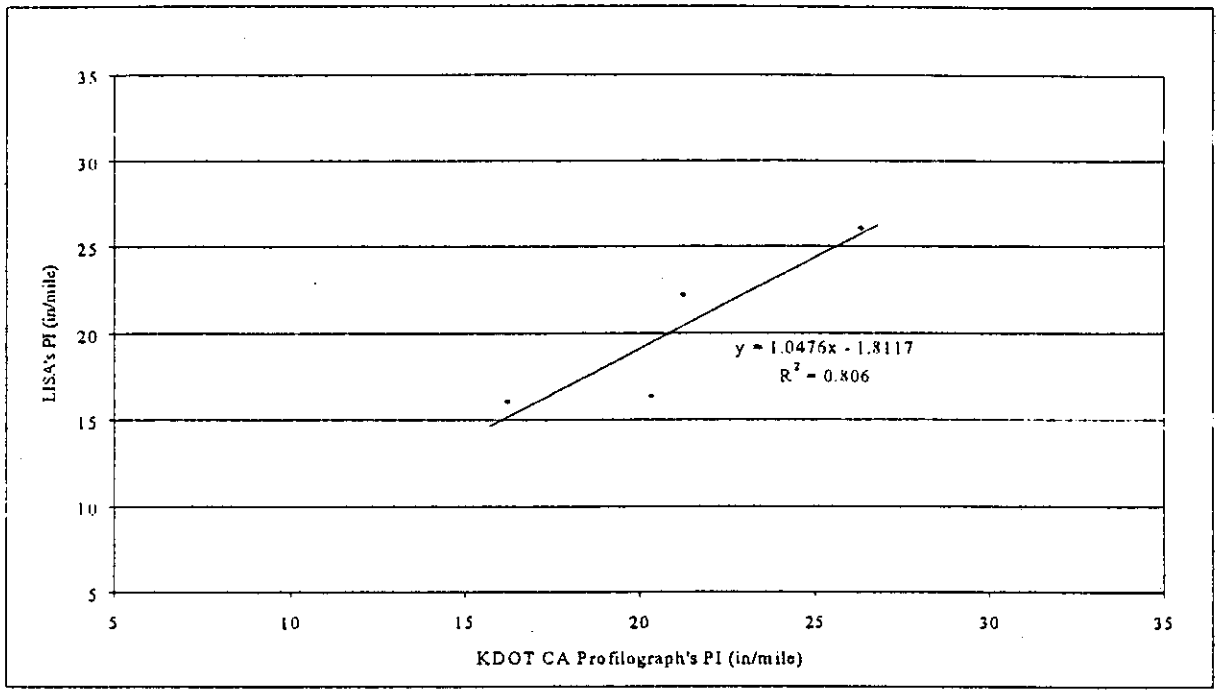


Figure A.26: Comparison between K. J. Law T6400 and KDOT California-Type Profilograph (Topeka, K-4)

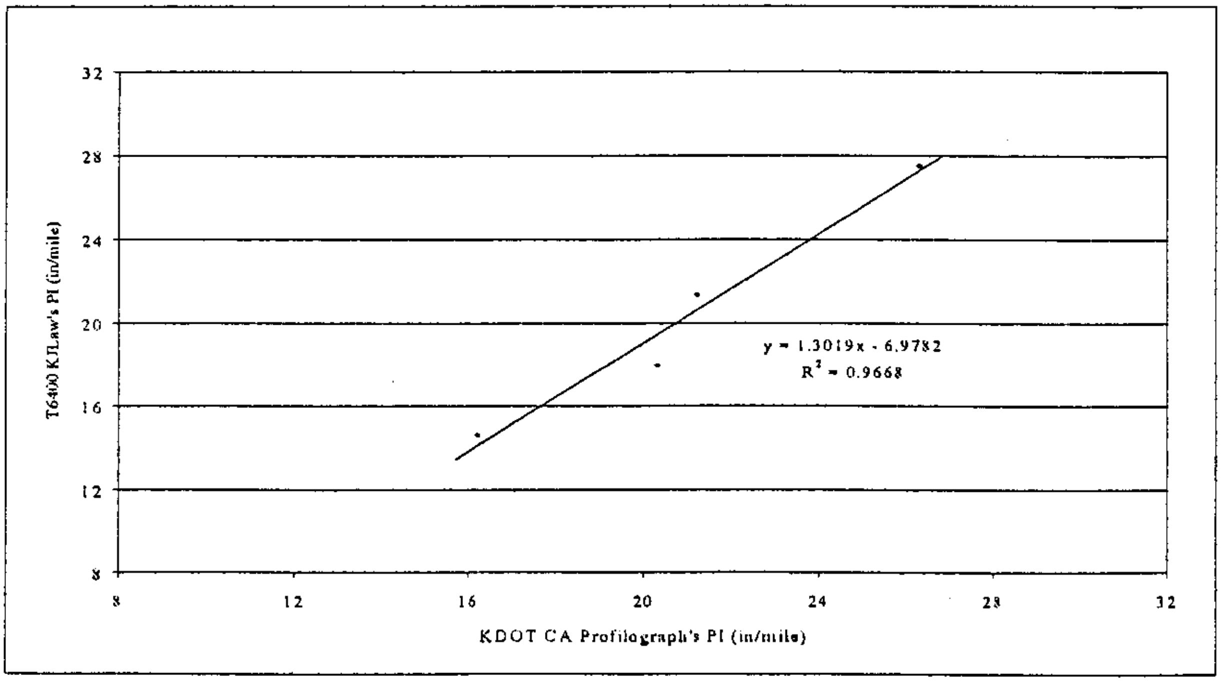


Figure A.27: Comparison between SSI and KDOT California-Type Profilograph (Exit 318, East)

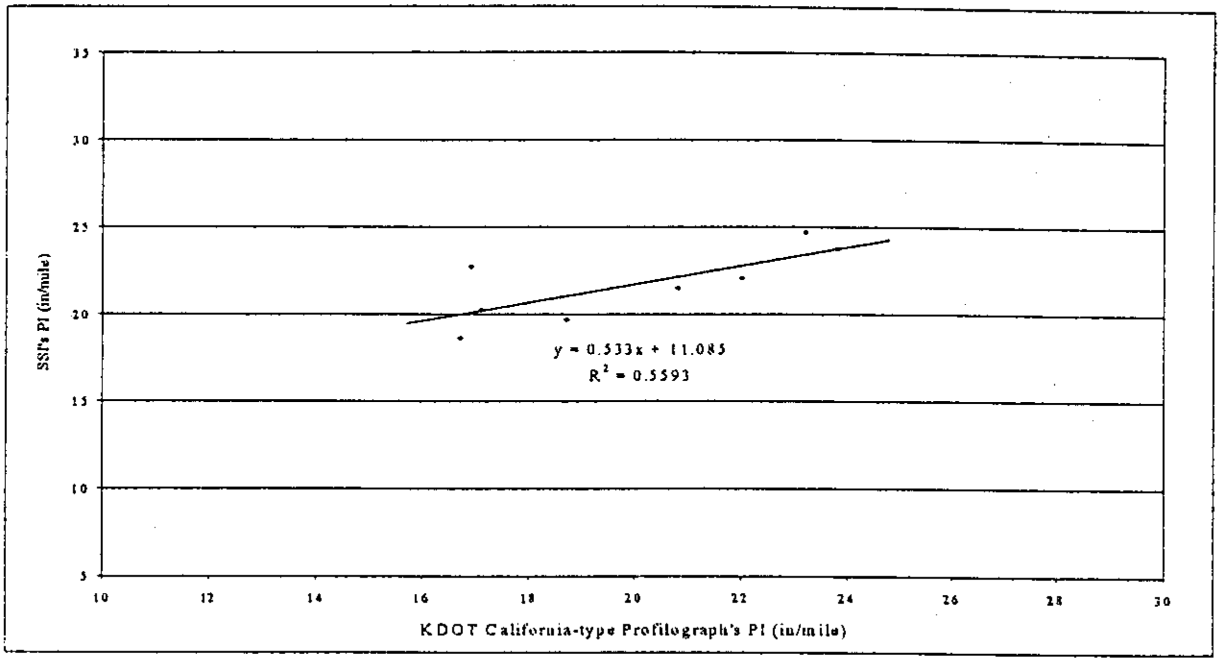


Figure A.28: Comparison between SSI and KDOT California-Type Profilograph (Exit 318, West)

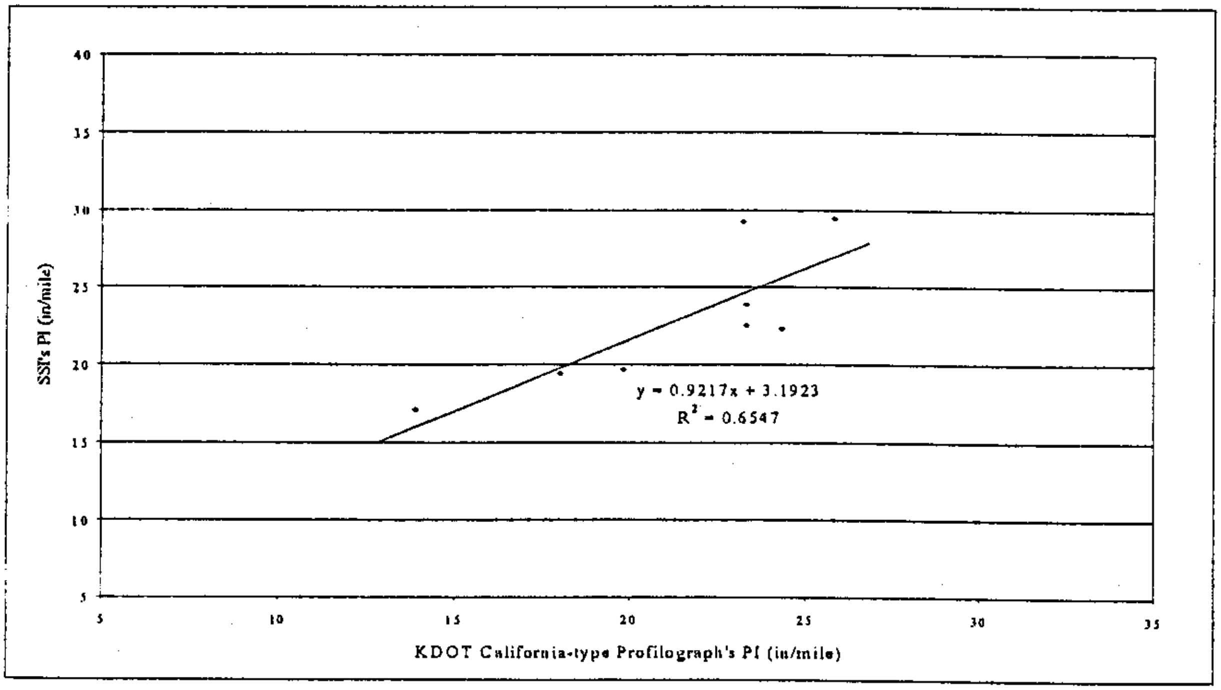


Figure A.29: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Marshall field)

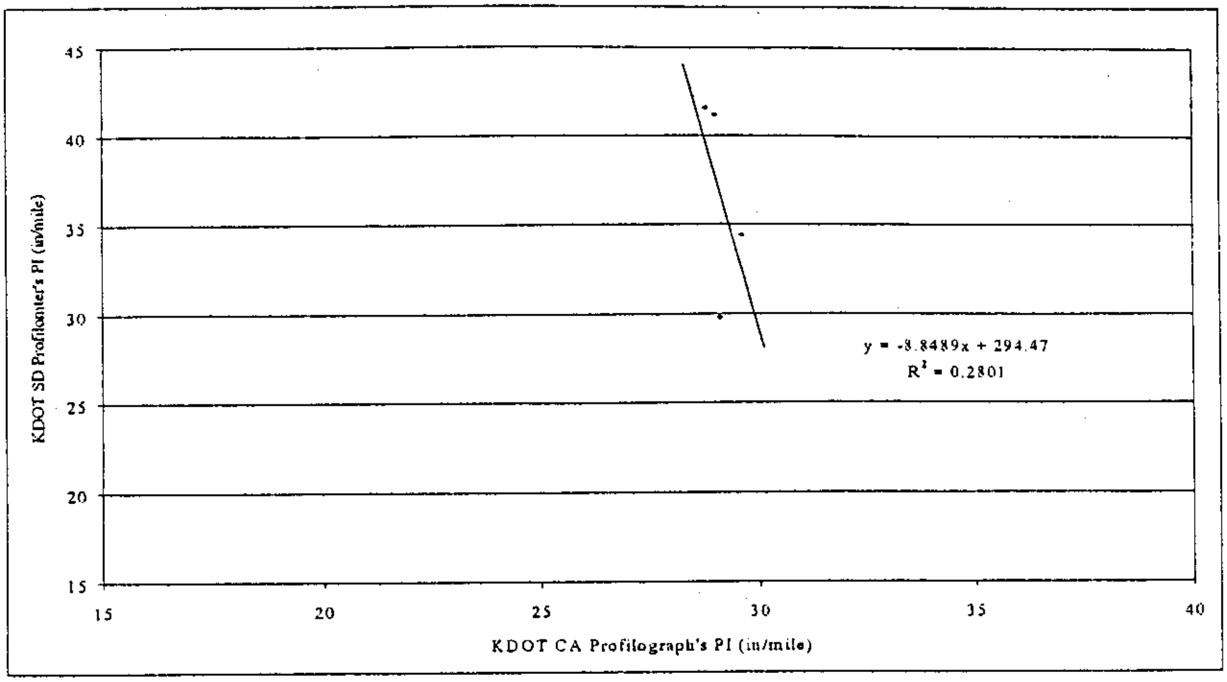


Figure A.30: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (McDowell Creek Road)

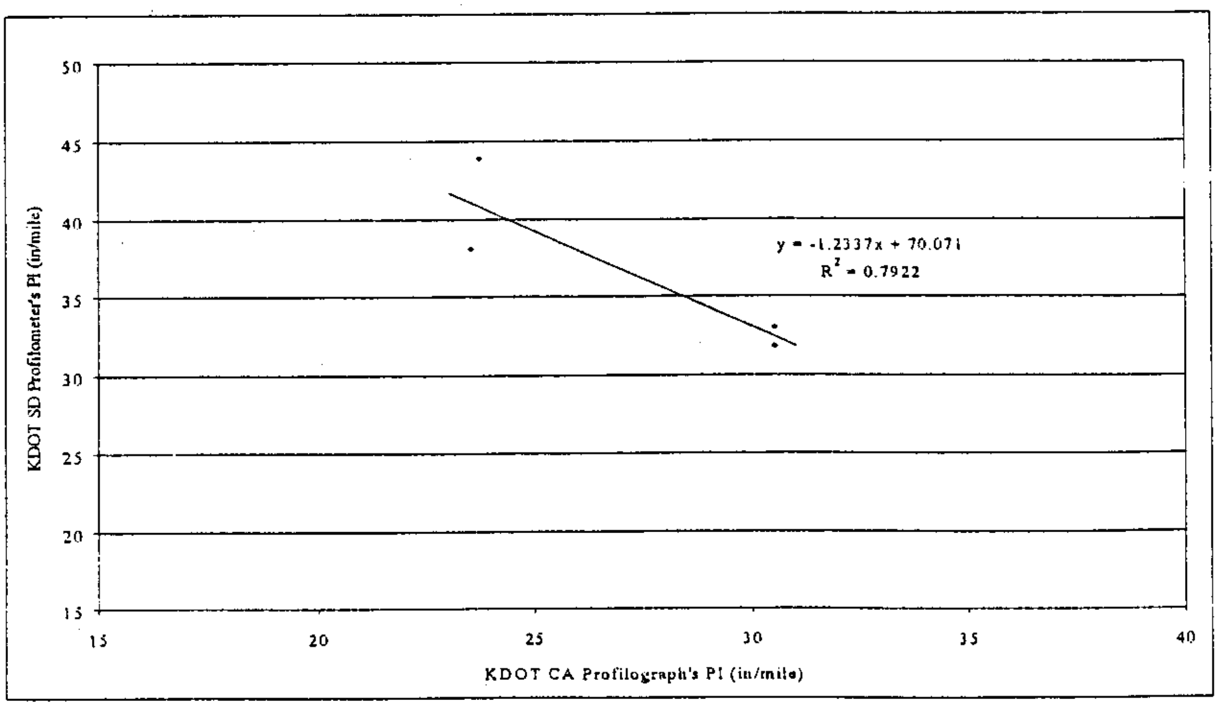


Figure A.31: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Wamego Exit, K-99)

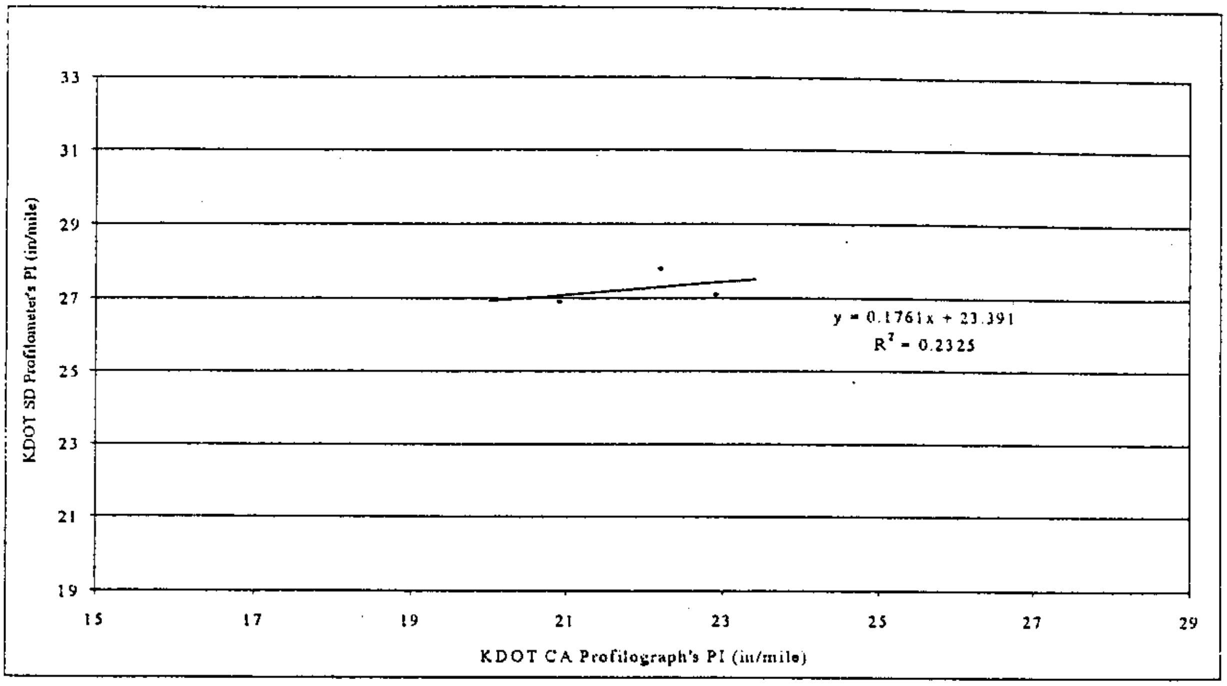


Figure A.32: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Wamego Exit, K-185)

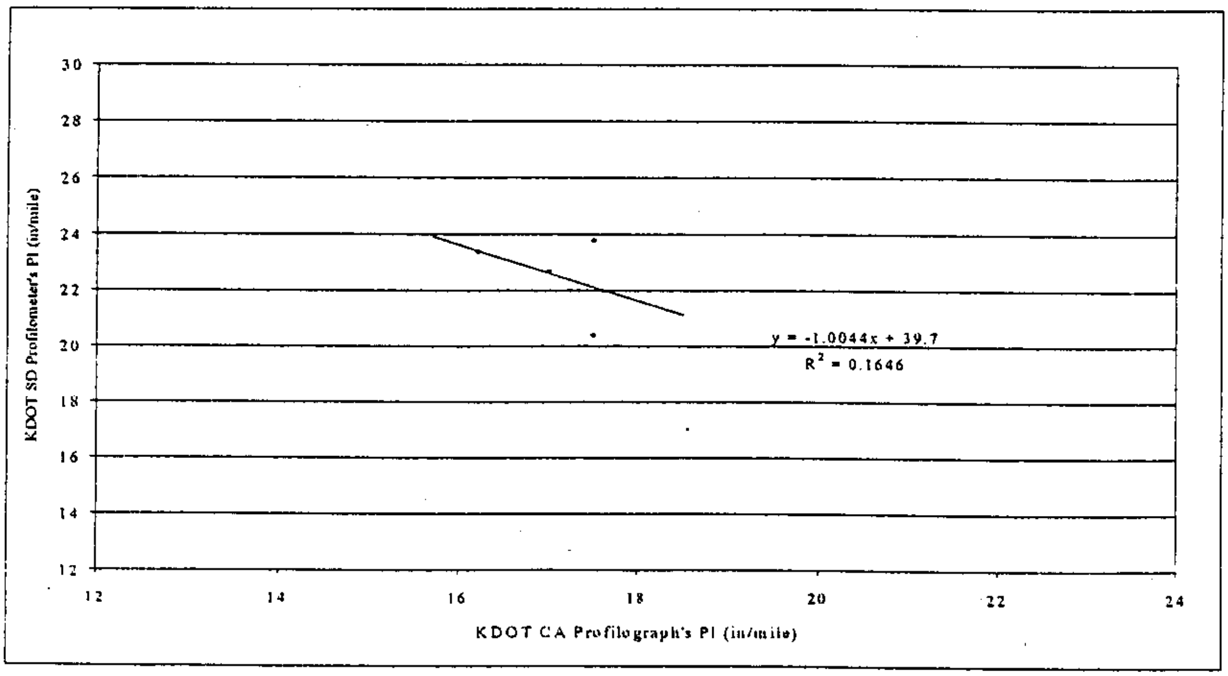


Figure A.33: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Topeka, Valencia)

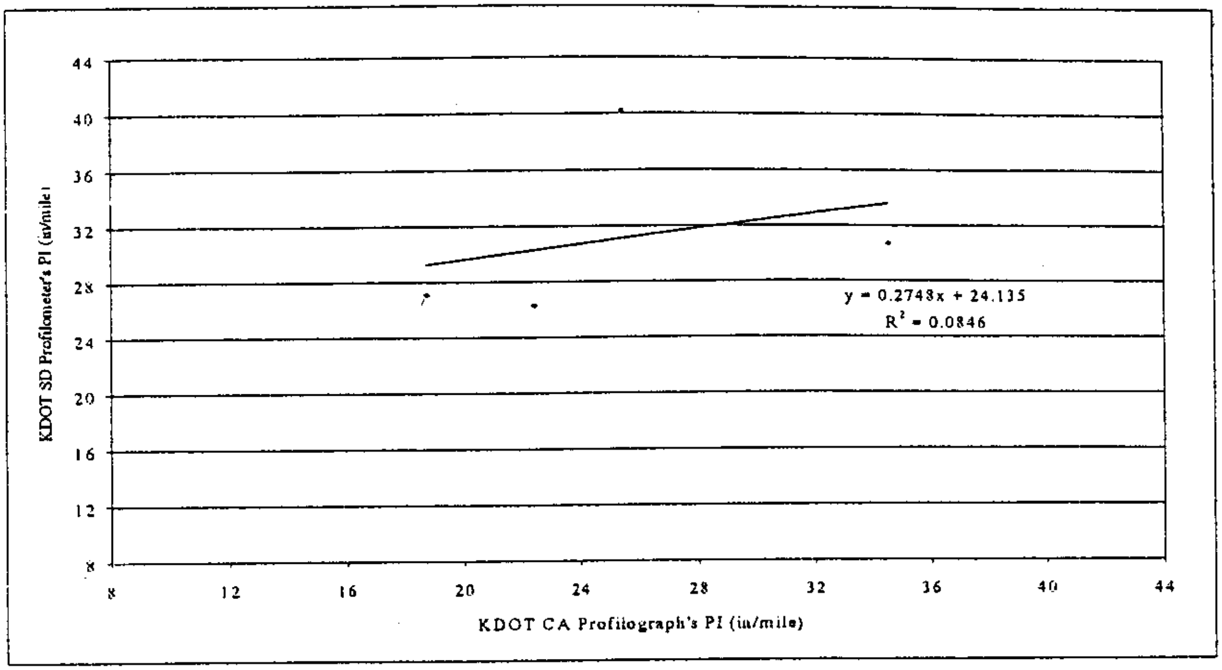


Figure A.34: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Topeka, K-4)

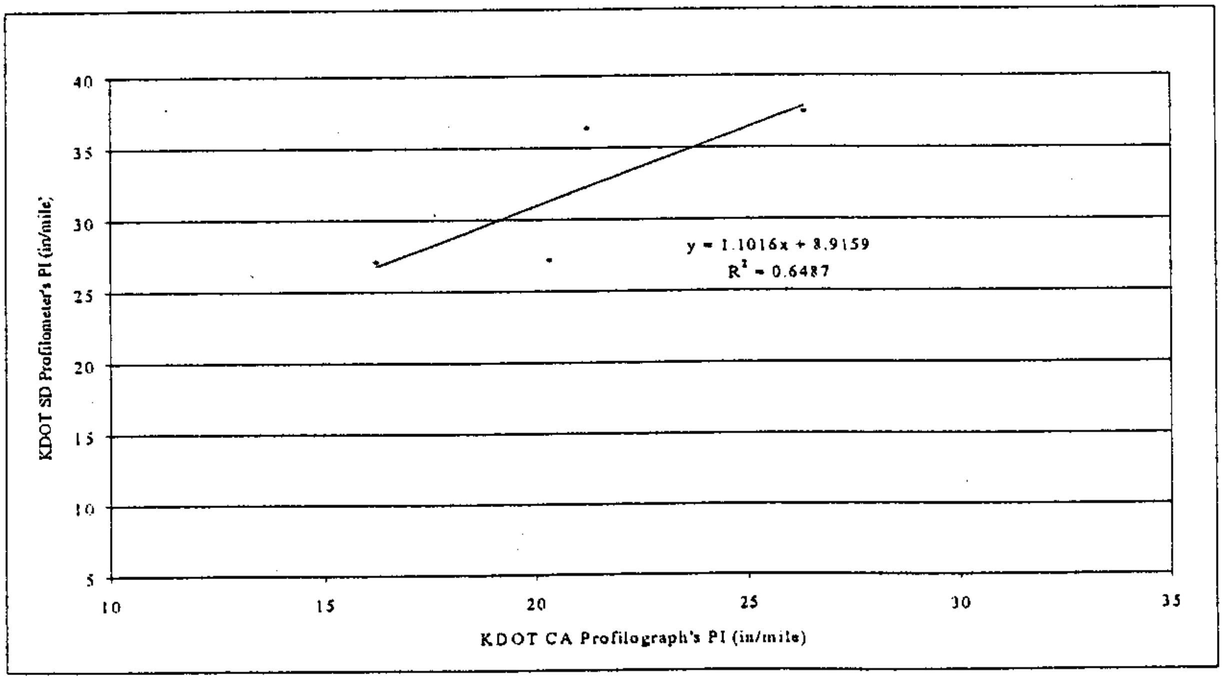


Figure A.35: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Exit 318, East)

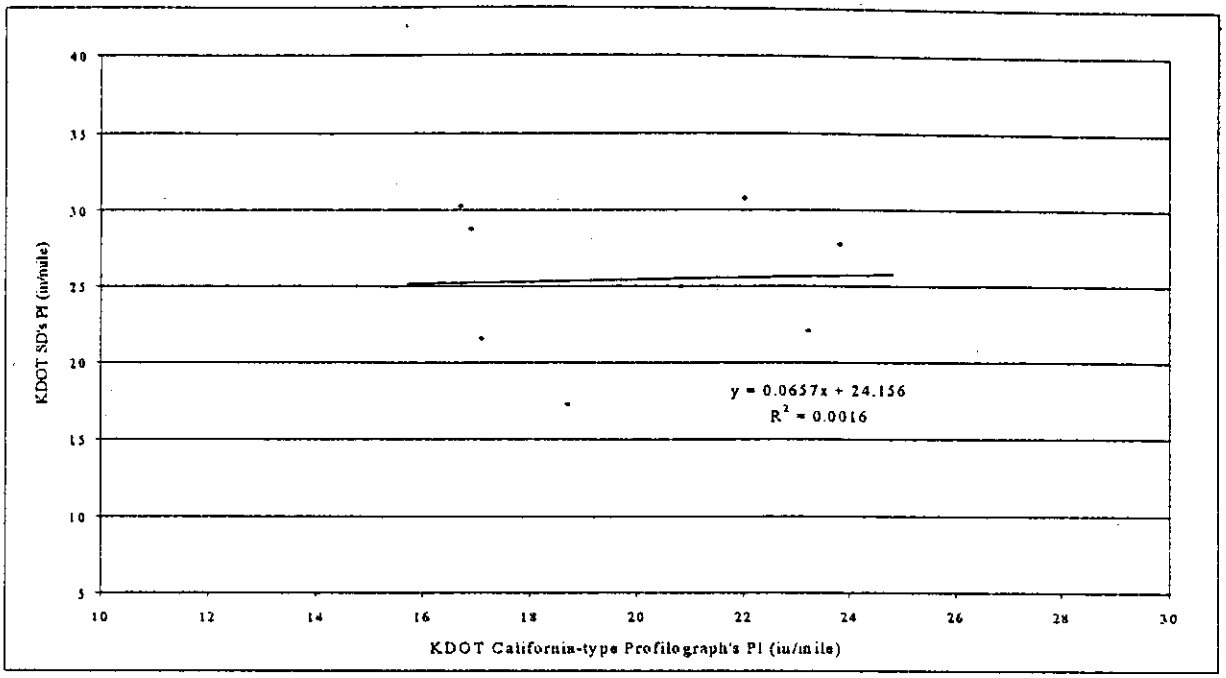


Figure A.36: Comparison between KDOT SD Profilometer and KDOT California-Type Profilograph (Exit 318, West)

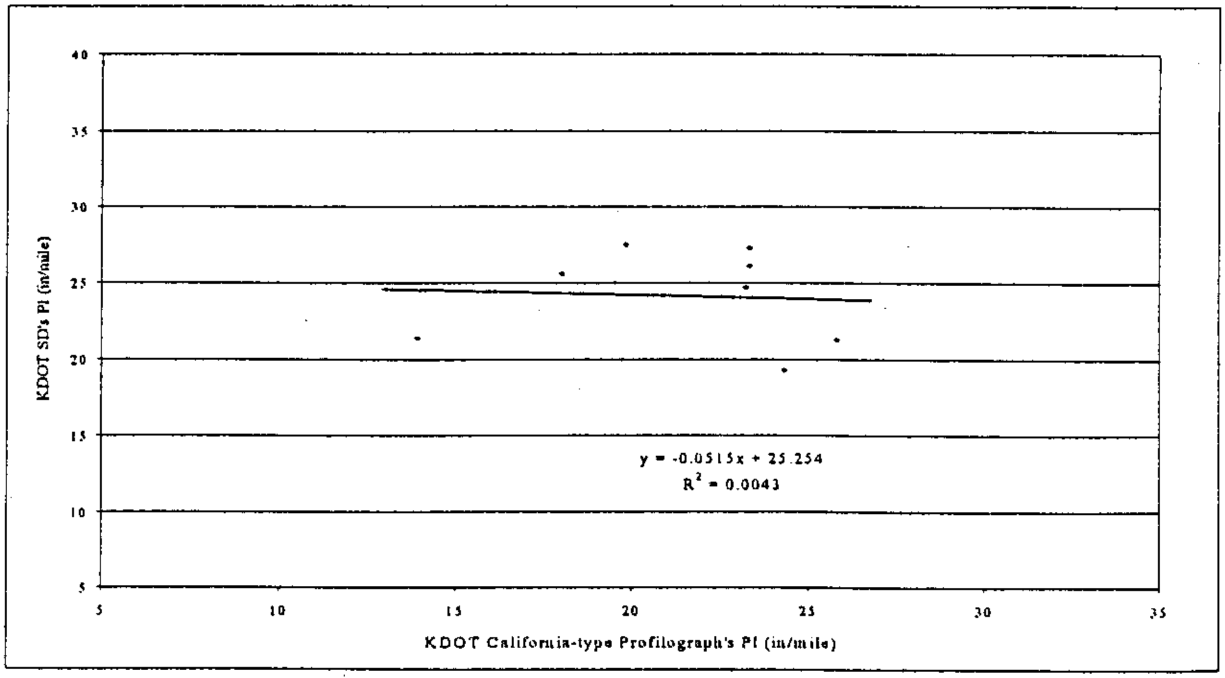


Figure A.37: Correlation between PI and IRI for ICC ATV

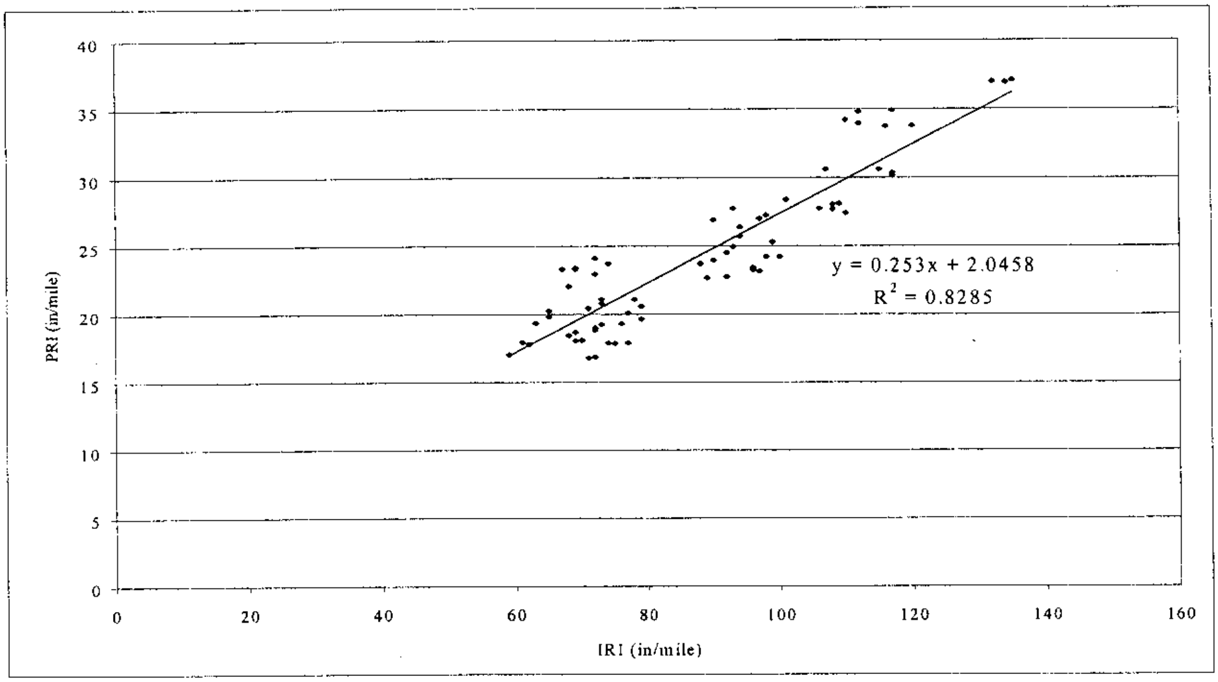


Figure A.38: Correlation between PI and IRI for Ames LISA

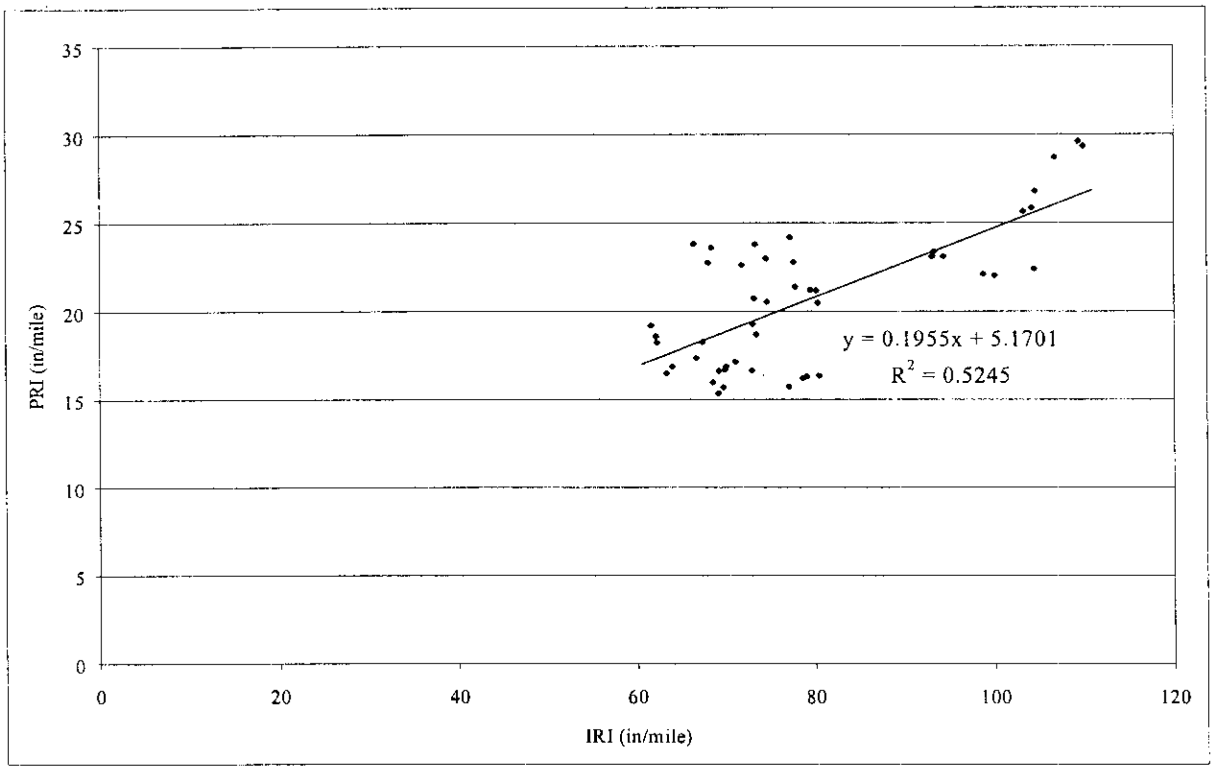


Figure A.39: Correlation between PI and IRI for K.J. Law T6400

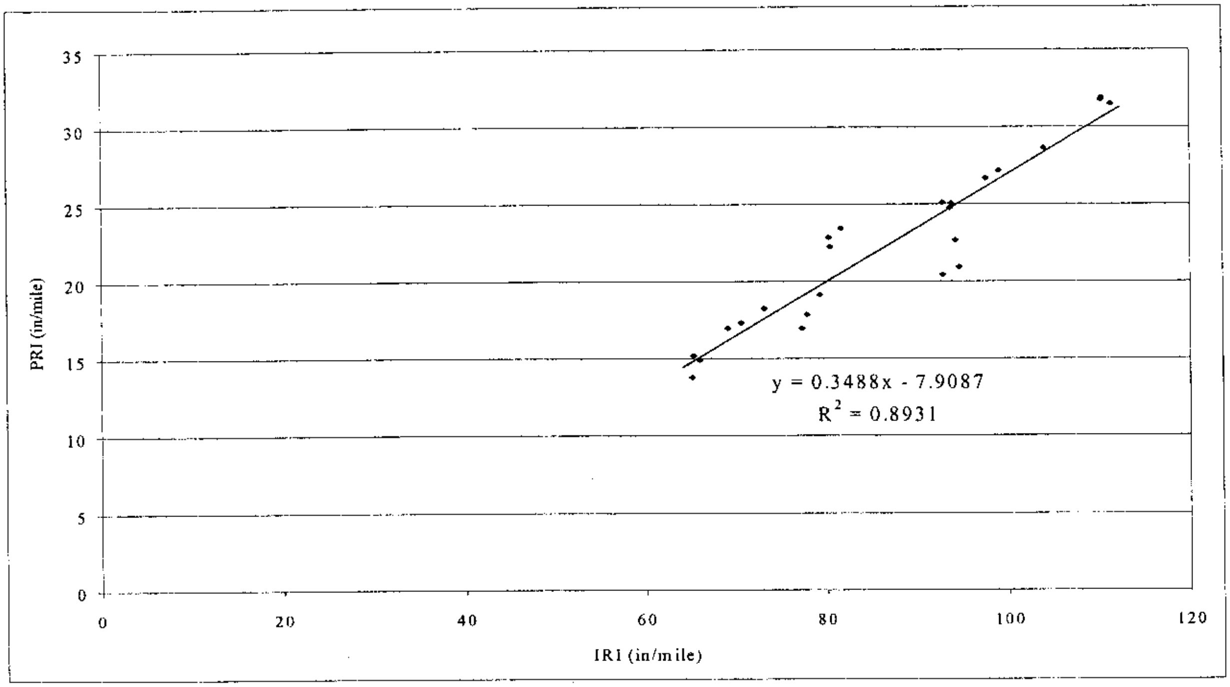


Figure A.40: Correlation between PI and IRI for SSI

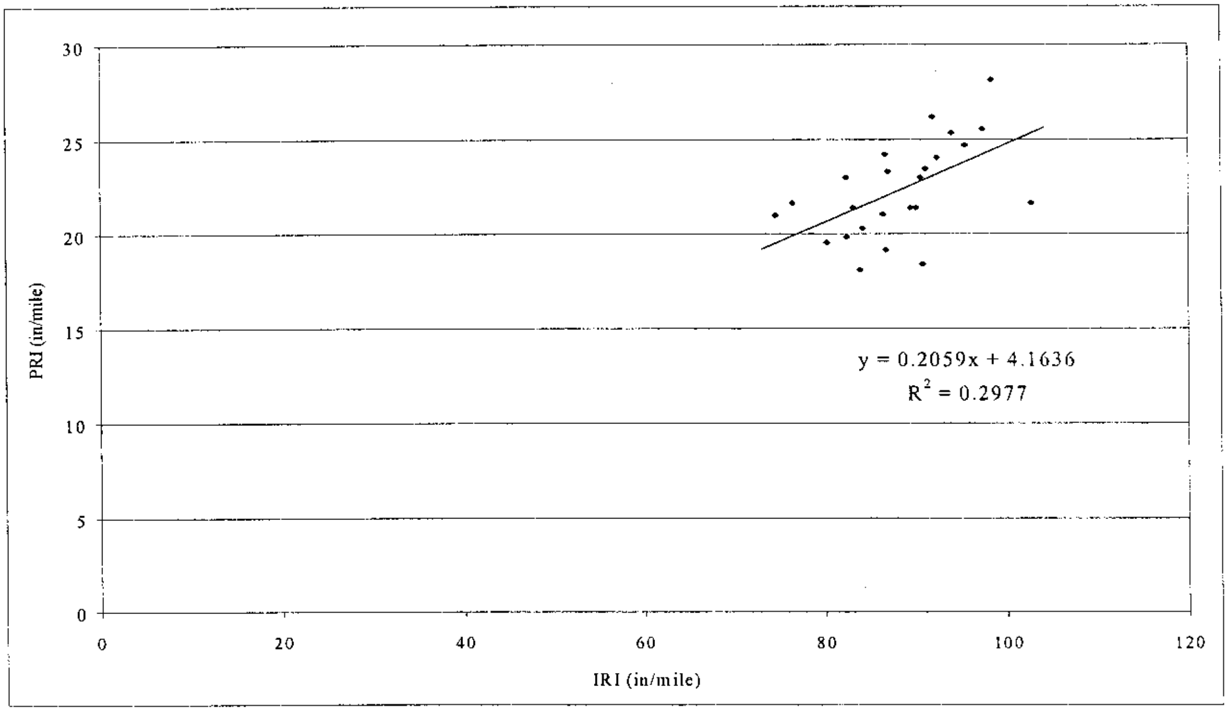


Figure A.41: Correlation between PI and IRI for K.J. Law T6600

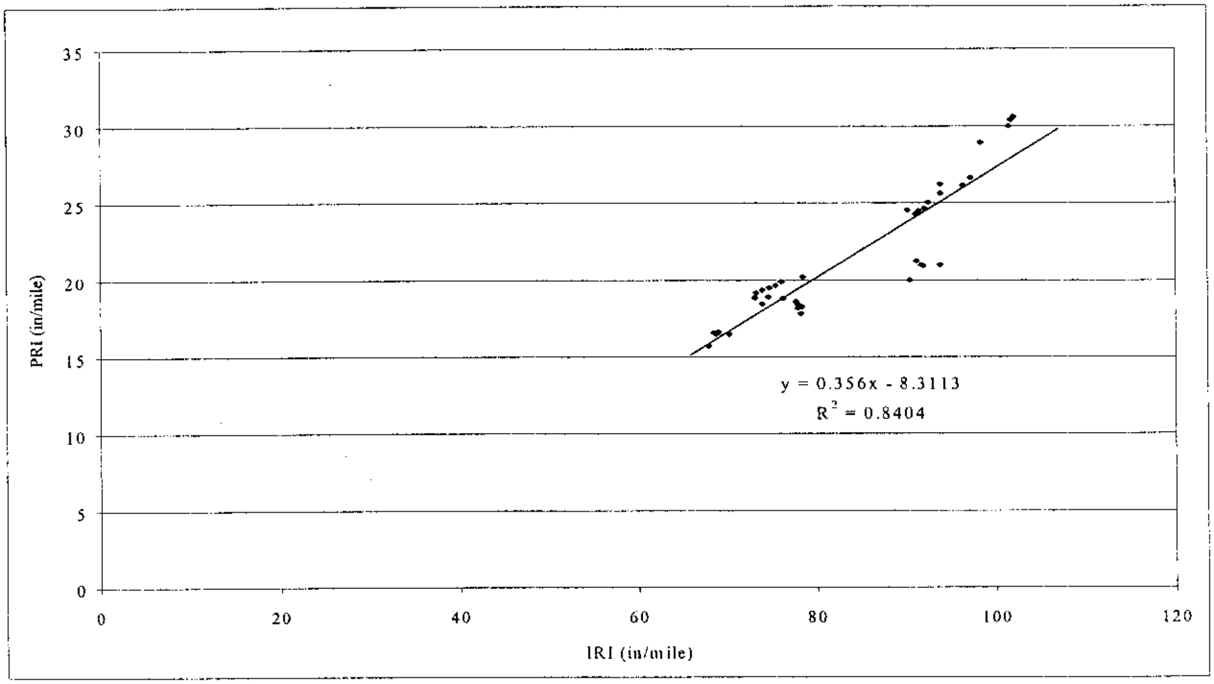


Figure A.42: Correlation between PI and IRI for KDOT South Dakota Profilometer