Evaluation of International Roughness Index Measurement Using Cell Phone App and Compare with Pavement Condition Index

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ABSTRACT

The research was conducted as a pilot project for Peoria County, Illinois, to collect the International Roughness Index (IRI) data using the cell phone app Roadroid. Two cell phones, Samsung J3 and Motorola G6, were used with dashboard mounts to check the IRI data's consistency. A Toyota Prius sedan car was used to host the cell phones for collecting IRI data. Eighty-two county roads were surveyed. Concurrently, a survey team of two inspectors collected pavement distress data for computing the Pavement Condition Index (PCI) for the same roads. For each road, four runs were made to collect the IRI data—the roads were surveyed in each of the two directions, using the two different cell phone models. The results indicate a strong relationship between the IRI value collected using the two different cell phones with an R-square value of 0.8087. The comparison suggests that the Roadroid app performed well to measure all levels of distressed pavements for most of the pavements surveyed in this study. However, the cell-phone-measured IRI data does not correlate with the PCI data collected for the same roads.

INTRODUCTION

Peoria County established a robust pavement management system. With the help of Bradley University (BU), they collected the Pavement Condition Index (PCI) data for the county roads for more than a decade. Based on the PCI data, the county has been regularly maintaining and rehabilitating its road infrastructures. Illinois Department of Transportation (IDOT) currently advocates establishing the International Roughness Index (IRI) as the pavement management system's indexing standard. Vehicle-mounted or hand-held automated laser devices are generally used to measure IRI in oppose to labor-intensive PCI measurement. For the last few years, laser devices have been using IDOT to collect Condition Rating Survey (CRS) data for the national and regional highways and quality control purposes. However, the CRS has been implemented since 1974. Only a few counties in Illinois use IRI in their pavement management system since the laser devices are expensive, sophisticated, and need skilled technicians to collect IRI data. On the other hand, the PCI data collection is time-consuming since road closure is required, and data collection is labor-intensive. Often, PCI data collection is not safe for the surveyors in high-volume county roads since the roads are mostly two lanes, and a few of the roads have a driving speed of 50 to 55 mph.

In 2016, a research project was initiated by IDOT on developing a guideline to evaluate low volume roads in terms of IRI, and the study explored the possibility of collecting IRI data using cell phone apps (Hossain and Tutunluer 2019). After completing the project in 2019, Peoria county showed interest in collecting IRI data using a cell phone app and establish a pilot project in Summer 2019 alongside collecting PCI data for their selected county roads.

Background of IRI

The IRI was established in 1986 by the World Bank (Sayers et al. 1986). It is produced using a quarter-car model and the longitudinal road profile. The total vertical movement of a standard passenger vehicle accumulated as an output from the mathematical model is referred to as the quarter-car model and is divided by the longitudinal profile length to produce the IRI value with units of in./mile or m/km. IRI is based on simulation of a standard quarter car's roughness response at a speed of about 50 mph. The model comprises a series of differential equations that relate a simulated quarter car's motions to the road profile. The roughness is the accumulation of the motion between the spring and the longitudinal profile length (Park et al. 2007). The output of IRI accumulation is the result of the spring constant (*K*) and dampening factor (*D*), shown in Figure 1 ("Pavement Technology Advisory—Data Collection Vehicles—PTA-T2" 2005).

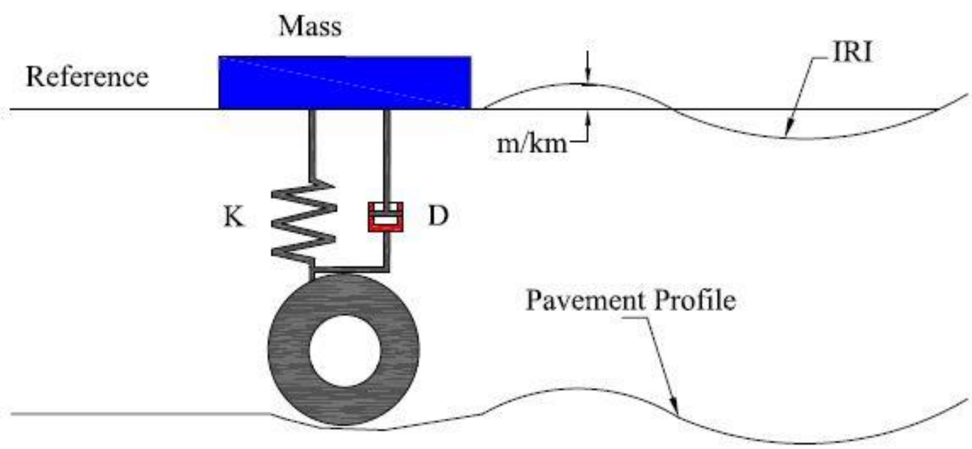

Figure 1. Typical quarter-car model (redrawn from "Pavement Technology Advisory—Data Collection Vehicles—PTA-T2" 2005).

Figure 2 shows the IRI standard values for various roads and surface types (Sayers and Karamihas 1998). The smaller values represent a smoother road, and higher values are indicative of a rougher one. Various vehicle-mounted or hand-held instruments are used to measure IRI.

Use of Cell Phone Apps to Measure IRI

With the advent of smartphones, various applications are introduced on a daily basis for public use; the applications are easy to access and free to use. They are often available without an internet connection on smartphones. As a result, smartphone-based applications are used to quantify road roughness, as they are equipped with sensors and accelerometers. Only a few studies could be found in the literature on measuring IRI using cell phones (Aleadelat et al. 2018; Arhin et al. 2015; Islam et al. 2014; Schlotjes et al. 2014). A built-in accelerometer in a cell phone can measure road roughness, and the relationship between the accelerometer data and road roughness has been shown to be linear (Douangphachanh and Oneyama 2014). Figure 3 shows a typical setup of a cell phone and the cell phone app's use to measure the IRI of pavement.

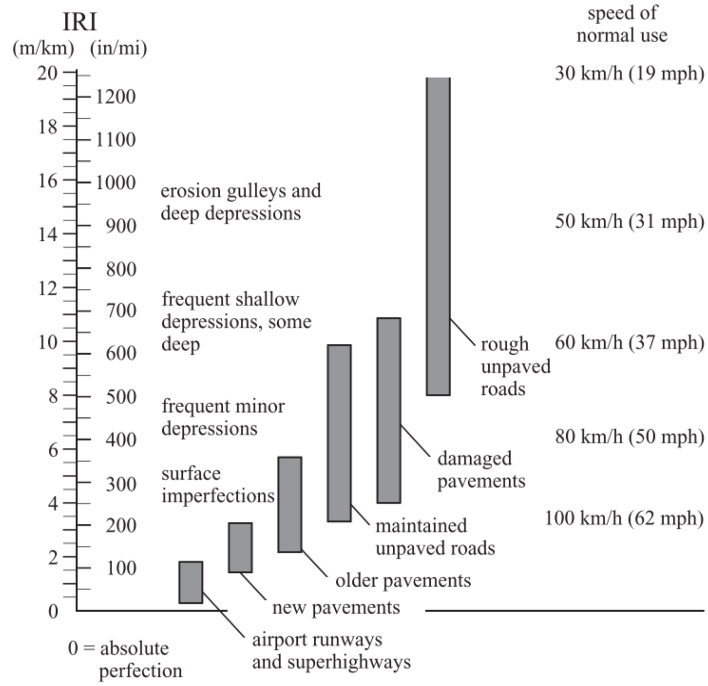

Figure 2. Variation of IRI for various road-surface types (Sayers and Karamihas 1998).

Figure 3. Use of cell phone app to measure the IRI of pavements (Belzowski and Ekstrom 2015).

A recent study conducted in Illinois showed that cell-phone-measured IRI and inertial-profilometer-measured IRI showed good correlations with the data obtained on smooth pavements at an operating speed of 50 mph (Islam et al. 2014). In Wyoming, another study indicated that the cell-phone-measured IRI data varied with speed; and the most variation was seen when the vehicle was driven at 50 mph (Aleadelat et al. 2018). Vehicle speed more than 60 mph is not recommended since excessive vehicle vibration will affect the IRI data. Researchers conducted a similar study in Michigan to measure IRI using their cell phone application; the initial state data showed low accuracy. However, a much higher accuracy was achieved when the driver took repeated data on the same road segment (Belzowski and Ekstrom 2015).

PCI Data Collection in Peoria County, Illinois

Peoria County is one of many Illinois agencies that face the challenges of maintaining and operating reasonable-quality pavements. For the Peoria County Highway Department (PCHD) to make effective decisions regarding pavement maintenance, rehabilitation, replacement, and improvement needs, a Pavement Management System (PMS) was established to meet these needs in 2008, through a partnership with faculty and students from BU. The PCHD's fully functional PMS was delivered in 2008 and included populated databases of pavement inventory, condition/distress data per the PCI, extensive photologs, and analysis capabilities in PAVER. Since then, the County has continued maintaining and updating the pavement management system and has contracted the BU research team each year from 2011 to 2020 to collect and enter updated pavement distress data on half of the County's road system per year. The specific roads included in each year's survey are identified and classified as the "odd-year" and "even-year" survey. In 2019 an additional component was incorporated into the PMS to include data collection for IRI using a cell phone application for data collection. To sustain the County's PMS and the system's benefits, it is critical that pavement condition/distress data be routinely collected and updated in databases. This will allow the PCHD to make continued decisions regarding pavement needs and improve PMS history's analysis and prediction capabilities.

The Peoria County roadway network consists of 300 lane-miles of the road across 19 townships, and the majority of roads are two-lane low volume roads. In the PMS system, the County's roadway network was segmented into 198 roadway sections consisting of 2,549 inspection units. In terms of pavement type, 94% of the sections are Asphalt Concrete (AC), and 6% are Portland Concrete Cement (PCC) sections. All of the PCC sections are included in the "even year" survey, regardless of what township they are located in. The characteristics of the County's system, also categorized into the "odd-year" and "even-year" surveys, are shown in Table 1.

Table 1. Characteristics of Peoria County road network and PMS surveys

Description	County Road System Total	County Road System in "Odd-Year" Survey	County Road System in "Even-Year" Survey
No. Townships	19	8	11
Lane Miles of Road	300	150	150
No. of Sections	198	90	108
No. Inspection Units	2,549	1,175	1,374
No. AC sections	186	90	96
No. PCC sections	12	0	12

The procedure initially established by the US Army Corps of Engineers and later standardized by (ASTM ASTM D6433-11 2011, Technical Manual: Pavement Maintenance Management 1982) was used in developing Peoria County's PMS, which includes the following:

- Segmenting the roads in the County's road network and identifying the sample inspection units to survey

- Conducting detailed walking surveys to collect pavement distress data by a data collection team, certified in flagger and safety training
- Entering the field data collected into the Paver software program, which uses distress data and a PCI rating from zero (failed) to 100 (excellent) for consistently describing a pavement's condition and for predicting its maintenance and rehabilitation needs

Roadway Segmentation

Inspections were performed for a randomly selected sample of units to analyze maintenance and rehabilitation alternatives for a given road section. Sampling plans were developed to allow adequate determination of the PCI and maintenance and rehabilitation requirements by inspecting only a portion of the sample units in a pavement section. These sampling plans can considerably reduce the inspection time and still provide the accuracy required, assuming that they represent the roadway section's overall condition. The same inspection units were to be surveyed over the years to maintain consistency. Thus, each sample unit needed to be identified concisely. Sketches of the sections within PCHD's jurisdiction were prepared to show the location, sample units, inspection units, and additional location information for the data collectors.

The County roads and their pavements were divided into components, including networks, branches sections, and inspection units. The networks represented the 19 townships in Peoria County. The branches are the roads within each of the township's boundaries. The branches were divided into sections based on the road characteristics' homogeneity and the roads' historical classification. The pavement sections were then divided into sample units. A sample unit is the smallest component of a pavement network and is used for pavement inspection. For asphalt-surfaced pavements, a sample unit is an area of approximately 2,500 square feet, plus or minus 1,000 square feet. For jointed concrete pavements with joint spacing less than or equal to 30 feet, the sample unit is an area of 20 slabs, plus or minus 8 slabs. The minimum number of sample inspection units to be surveyed was determined using documented graphs based on the total number of inspection units for each branch and the PCI range. The inspection units to be surveyed were randomly selected using a systematic sampling procedure based on the spacing intervals and a random start. When the total number of samples within the section is less than five, every sample unit should be surveyed. If it is greater than five, the minimum number of samples determined per the outlined process should be surveyed. The inspection units for the County's network were then identified and located on sketches.

Data Collection and Calculation of PCI

Prior to collecting field data on Peoria County roads, the inspectors became certified through the Flagger Safety Training course to safely conduct pavement inspections. In addition to the flagging instructions, one member of the two-person team was instructed to focus on traffic to ensure the safety of the team by adhering to the following precautions:

- Be aware of your surroundings; listen and watch for approaching vehicles
- When an approaching vehicle is detected, make sure you move to the shoulder
- ALWAYS wear your safety vest
- Set-up the cones and warning signs to provide a warning to motorists
- Position the work vehicle in a manner to protect the survey team - upstream of the inspection area to serve as a buffer

Before the inspectors leave for the field, they obtain the segmentation sheet, review the location of the segments assigned and obtain additional directions/maps if necessary, make copies of the data collection forms needed for the assigned road, and load the safety and measuring equipment into their vehicle.

A two-person team then conducted detailed walking surveys to identify each distress's type and severity along randomly selected sample inspection units. A total of 39 distress types listed below (20 types for asphalt pavements and 19 for concrete pavements) are defined with three levels of severity for each distress being high, medium, or low based on quantifiable measurements of the deterioration (Asphalt-Surfaced Roads and Parking Lots: PAVER™ Distress Identification Manual 2009, Concrete Surfaced Roads and Parking Lots: PAVER™ Distress Identification Manual 2009).

To begin the data collection, the inspectors walk over each sample unit, measure each distress type and severity, and record the data on data collection forms for asphalt-surfaced pavements and/or jointed concrete pavements. One form is used for each inspection unit. Details on what measurements to take for specific distresses are included in the Asphalt-Surfaced Roads & Parking Lots Distress Identification Manual (2009) and the Concrete Surfaced Roads & Parking Lots Distress Identification Manual (2009), which are available to the teams at all times and referenced while performing the inspections in the field. They are specially designed for use during the inspection and are indexed by distress type for user convenience. Descriptions of each distress type are summarized, and measurement criteria for each Severity Level being High, Medium, or Low, instructions on How to Count them, and photographs for each severity level to illustrate the various conditions and distresses. The detailed walking surveys are performed for all inspection units along all the sections and branches identified for the "odd-year" or "even-year" survey of the county roads.

Traffic cones are used to delineate the length of the inspection unit nearest to the shoulder. A tape measure is laid out on the road's side to aid in extracting the pavement distresses' measurements. Photographs are taken of each inspection unit, and any high severity distresses observed in the field to update the County's photo-log of the inspection data.

The distresses observed and collected in the field are summarized and entered into the Paver software program, which calculates the PCI. PCI values are obtained for each inspection unit and then aggregated to represent the PCI at various levels - for each road section, for each branch, for each network, and an overall rating. The Peoria County engineers then systematically use the PCI data to make maintenance and rehabilitation decisions to improve their roads' pavement condition.

OBJECTIVE AND SCOPE OF THE WORK

The study's purpose is to collect IRI data using a cell phone app for selected roads in Peoria County, Illinois, and check the IRI data's consistency. Roadroid cell phone app was used in this study. Roadroid app is user-friendly. The data collection is convenient, and the data is uploaded into their website in a few steps. Various data visualization can be obtained from the Roadroid website. The data can interpret easily into multiple formats from the Roadroid website. Two cell phones, Samsung J3 and Motorola G6, are used and attached with two sturdy dashboard mounts. A Toyota Prius sedan car was used to collect the IRI data.

A database of 89 county road sections is taken from Peoria County. There are two groups of students who worked on this project, one group of students collected PCI data, and another group collected IRI data. The IRI data collection group could survey 82 road sections since construction work was conducted during Summer and Fall 2019. The following results are based on 82 road sections.

IRI DATA COLLECTION METHODOLOGY

Figures 4(a) and (b) show the cell phones set up in the Toyota Prius sedan car. Two students collected the IRI data; one student drove the vehicle, and another student operated the Roadroid app and the cell phones. The students collected the data during the off-peak time to reduce interference with local traffic. The off-peak time was chosen since most of the roads surveyed for this study were two lanes (i.e., one lane, each direction), and the data collection speed was relatively low compared to the posted speed. The average lowest speed recorded by the Roadroid app was 8.0 mph., and the average highest speed was 30.0 mph.

(a)

(b)

Figures 4(a) and (b). IRI data collection using Motorola G6 (left) and Samsung J3 (right) cell phones.

Four sets of data were collected; two cell phones and two data were collected for each direction, i.e., North to South or East to West, and returned directions. For example, the car drove North-bound, two cell phones collected one set of data, and while the vehicle returned following South-bound, two cell phones collected another set of data. The car again drove to North-bound and collected data, and returned to South-bound and collected data. The North-bound and South-bound data are then averaged, and one IRI value was calculated for each road and recorded alongside the PCI data collected by another group of students. The IRI data collector group coordinated with the PCI data collector group before visiting each site and confirmed their starting and ending data collection location.

The cell phone data variability can be seen in Figures 4(a) and (b). According to Figure 4(a), the green horizontal bars on both cellphone screen shows that they are collecting consistent IRI data. As shown in Figure 4(b), the green and yellow horizontal bars on the Motorola phone and green horizontal bars on the Samsung phone show that they are collecting slightly different IRI data. The difference may be due to sensor sensitiveness in two cell phones, or the vehicle vibration is not equally distributed into the vehicle frame. For this reason, averaging four sets of data would normalize the variation into the IRI data.

IRI DATA VISUALIZATION

The IRI data needs to upload to the Roadroid website for more visualization. Figure 5 shows an example of one of the types of data visualization for N Big Hollow Rd. The Figure shows locations where the roads are in good, satisfactory, unsatisfactory, and poor conditions and the location of various ranges of IRI values. The location interval can be varied, such as the pavement condition can be visualized every in 100 m or 200 m intervals. The IRI data is available in the SI unit on the Roadroid website.

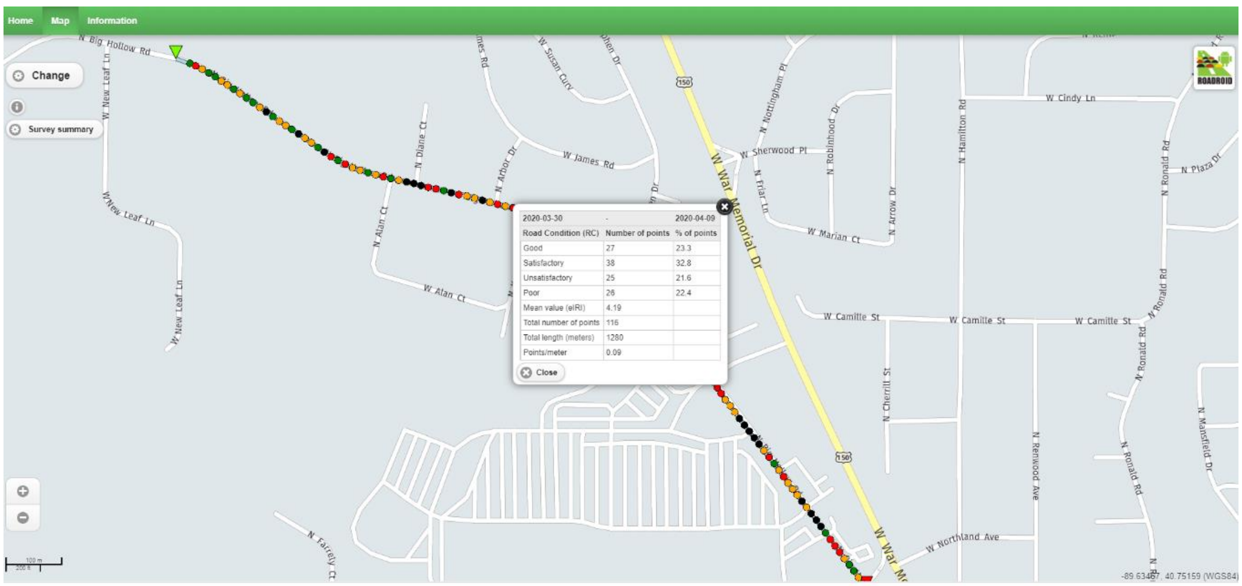

Figure 5. Various road conditions and IRI data visualizations on the Roadroid website.

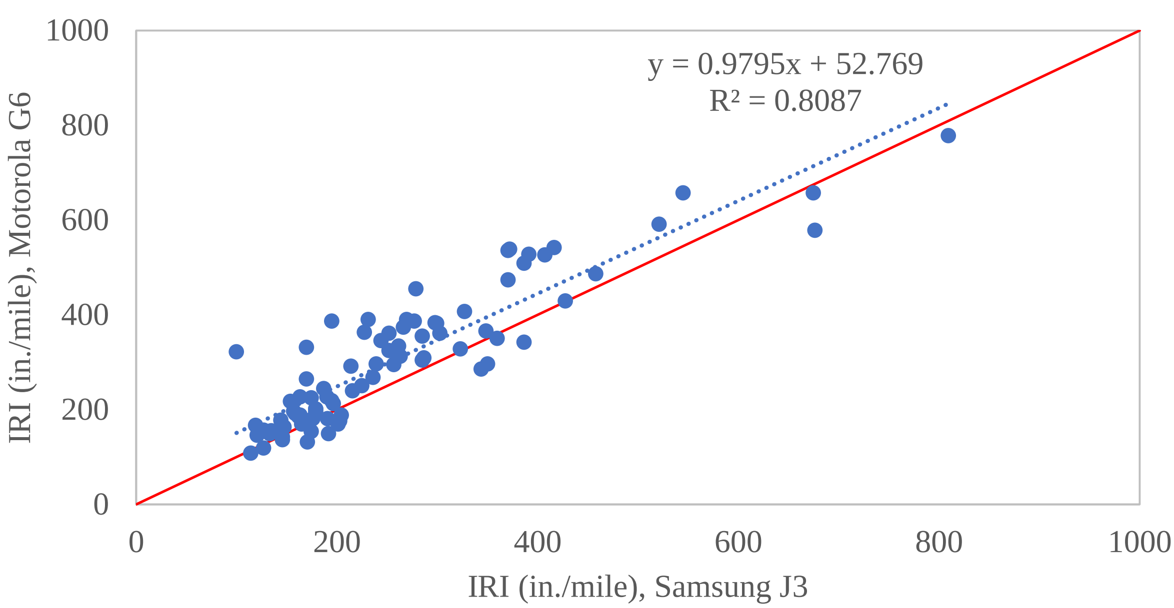

Figure 6. Comparison between IRI values measures by the Roadroid app using Samsung J3 and Motorola G6 cell phones.

RESULTS

Figure 6 shows the comparison between IRI values measured by the Roadroid app using Samsung J3 and Motorola G6 cell phones. The lower IRI value means less distressed pavement. According to the graph, the R-square value is 0.8087, which means a strong correlation was observed between the IRI values measured using the two cell phones. The blue dotted line shows the linear regression line, and the red line shows the line of equity. It could be seen that both cell phones show fair agreements as most of the pavements have low to moderate distressed conditions, such as IRI value ranges from 150 to 400 in./mile. Even a few pavements have a high distressed condition, such as an IRI value greater than 400 in./mile; the IRI values are close to the line of equity. The comparison indicates that the Roadroid app performed well to measure all levels of distressed pavements for most of the pavements surveyed in this study.

Figures 7 and 8 show the relationship between PCI and IRI data. The IRI data were measured by the Roadroid app using Samsung J3 and Motorola G6 cell phones. Higher PCI value and lower IRI value mean less distressed pavement and vice versa. According to the graph, the R-square values are 0.0248 and 0.0577, respectively, which means the linear regressions do not show a strong correlation between PCI and IRI values. Thought other research shows a better correlation between IRI and PCI data (Arhin et al. 2015, Hasibuan and Surbakti 2019). The blue dotted line shows the linear regression line, and the red line shows the line of equity. The data points close to the line of equity show the best correlation between the PCI and IRI data. However, there are lots of data that are scattered and away from the line of equity. Though the Motorola G6 cell phone collected IRI data shows a better correlation than Samsung J3, the R-square value is not significantly different.

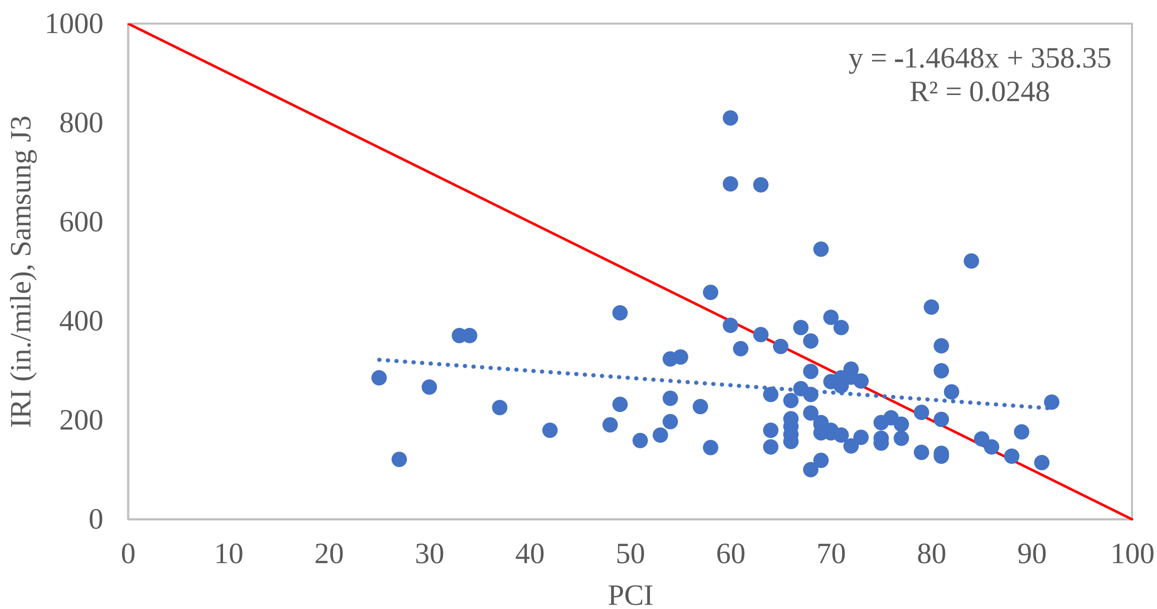

Figure 7. Comparison of PCI vs. IRI data; the IRI data were measured by the Roadroid app using the Samsung J3 cell phone.

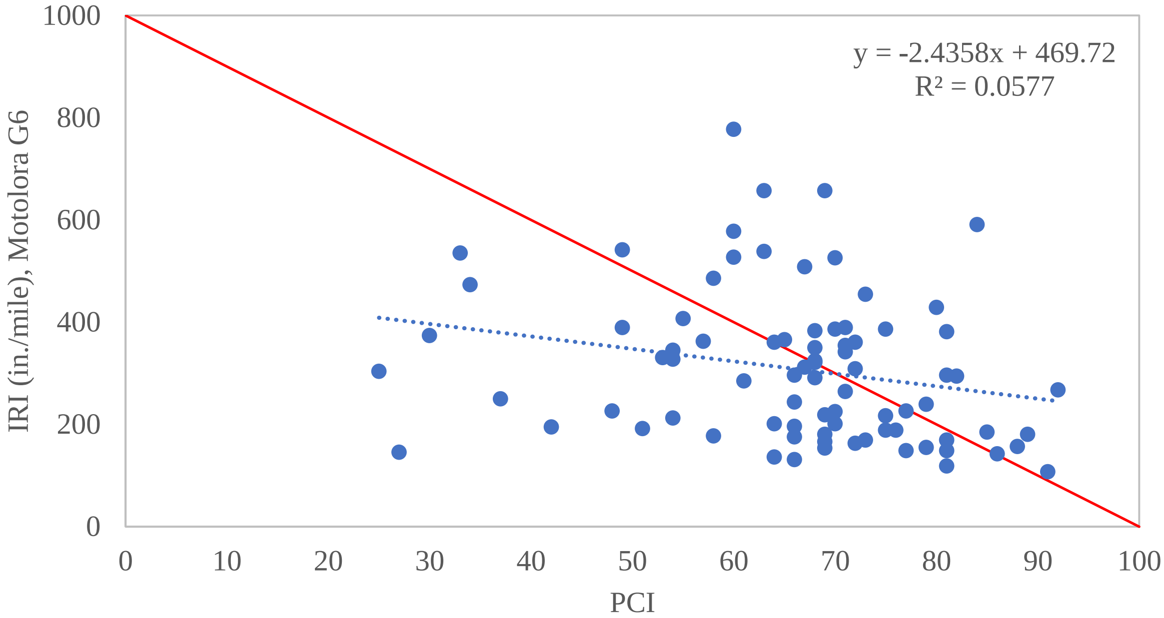

Figure 8. Comparison of PCI vs. IRI data, the IRI data were measured by the Roadroid app using the Motorola G6 cell phone.

CONCLUSIONS

The study is done as a pilot project for Peoria County to collect IRI data using cell phone app Roadroid, alongside PCI data for selected roads in the county. IRI is well-established indexing to measure pavement conditions as oppose to PCI. PCI data collection is time-consuming and labor-intensive, and often time lane closure is needed. IDOT collects IRI data using vehicle-mounted or hand-held laser devices that are expensive, sophisticated, and skilled technicians required. For this reason, a less expensive but reliable method, such as a cell phone app, was used in this project. Cell phones can mount in a car or truck, and the vehicle can drive at the near posted speed, and the data collection is faster.

Two cell phones were used to check the consistency of the IRI data. There are various cell phone apps available in the app store to download. However, currently, only Android operating system-based apps are available for download. A well-established app Roadroid is used in this project. In this project, the Roadroid app shows good agreement while collecting IRI data using Samsung J3 and Motorola G6 phones. The R-square value is 0.8087. However, it is seen that the cell phone app measured IRI, and PCI data do not show a strong correlation.

It is essential to check the cell phone data collection's consistency using the Roadroid app for future years. It is expected that the county roads will show more distresses in the coming years due to traffic and climate, and IRI value will increase along with that. The Roadroid app with cell phones should capture the increase in IRI value in future years.

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