Proceedings of the Eastern Asia Society for Transportation Studies, Vol.10, 2015

Estimating Road Roughness Conditions Using Ubiquitous Smartphones and Geographic Information Systems and its Application to Road Network Planning in the Philippines

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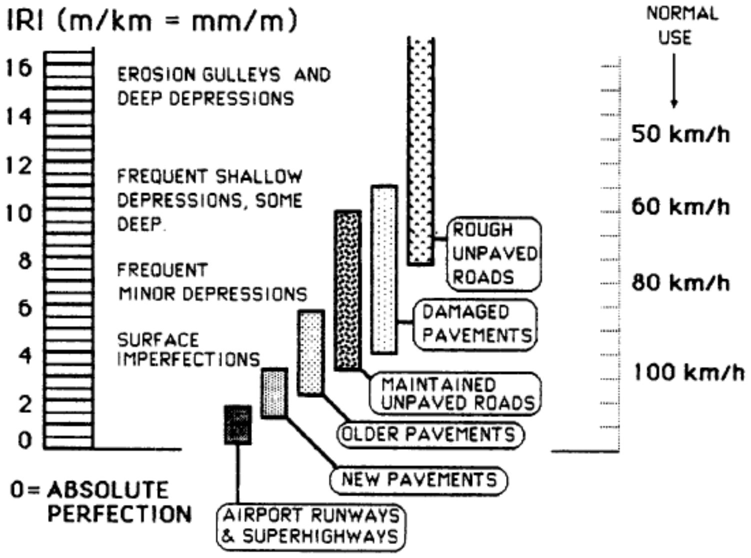
Abstract: The World Bank established the International Road Roughness Index (IRI) as a standard to measure road roughness. Although road inspection vehicles equipped with multiple sensors costing several millions of pesos can effortlessly measure IRI, developing countries find this steep price to be a challenge for evaluating and managing their road systems. This paper therefore aims to develop an alternative method to measure road roughness using ubiquitous smartphones and Geographic Information Systems (GIS). The proposed methodology is based on data collected by smartphones which are processed using GIS and compared with existing IRI measurements to estimate road roughness measurements of different road types. The paper likewise explores the proposed methodology's application and integration to road network planning in the Philippines.

Keywords: Road Roughness Index, Smartphones, GIS, Road Network Planning

1. INTRODUCTION

Road roughness measurements were made simpler with the very insightful 1986 technical publication from the World Bank which outlined certain guidelines to ascertain road roughness through vehicular response at an average speed of at least 80 km/hr (Sayers et al., 1986). Prior research projects in Brazil and the National Cooperative Highway Research Program helped create this comprehensive guideline's core concepts and applications. As a result, the International Roughness Index (IRI), a scale of roughness levels, was developed and is now used as a reference for describing roads internationally.

Based on vehicle response, the road roughness is considered as a measure of riding comfort across any given road. Furthermore, considerable expectations are set for various types of roads, from the low index values of airport runways requiring the smoothest pavement condition up to the high index values of rough or undeveloped roads (Figure 1).



Source: Sayers et al. (1986)

Figure 1. The IRI Scale

In the 1970s, road roughness measurements for statistical analysis are hot topics of interest. One of the earliest studies was done by Karan et al. (1976) in which data were recorded on roughness, volume to capacity ratios and spot speeds using radar at several locations. The assessment of road roughness is mostly a subjective one, consisting of passenger ride evaluations which may vary from person to person according to their respective level of personal threshold for discomfort (Morosiuk et al., 2004). During this time, vehicle technology has not been as developed and the roughness of roads played a big hand in vehicle selection across locations. Apart from this, the methods were quite crude considering the capability of measurements at that time. The initial studies on road roughness were nonetheless crucial employing statistical methods and multi-location observations and laid the groundwork for incoming technological advancements.

The full bloom of road roughness measurements and studies were observed in the 1980s, preceding the development of standards such as the widely practiced Highway Development and Management. It was in the Brazil study (i.e., the International Road Roughness Experiment) that the concept of IRI was first officially addressed - being marked as a way to standardize the descriptions of road roughness based on field measurements. Prior to this, previous studies made use of multivariate analysis with roughness as only one of the factors being observed. It was also during this time that the average rectified slope (ARS) or vertical displacement of the chassis to the axle on the road section was introduced. This was more focused on vehicular vertical change with respect to road roughness. Later, these road roughness measurements from earlier times paved the way for the International Roughness Index (IRI), a more comprehensive and focused approach to measuring road roughness.

A new Roughness Index called Adjusted Roughness Index (RI) was introduced in the latest version of the Highway Development and Management Series (Bennett, 2001). This claims that IRI levels at the range of 3-4 are absorbed or rendered negligent by modern vehicles. But at this moment and for analysis at the national level, the IRI is still more widely practiced globally. These new developments aim to take a crack at the intricacies of IRI, possibly further segmenting the index values in a road segment as a high-impact or low-impact factor.

Other modifications in estimating road roughness have been made to include latest technologies, such as those done by Chang et al. (2009) which used automated robotic devices to measure road roughness in partnership with a standard GPS device. The use of artificial neural networks in generating IRI values in a road network is also a subject of much interest in recent times. For example, Lin et al. (2003) and Ferregut et al. (1999) used back propagation neural network to predict IRI of pavements.

The proliferation of probabilistic, empirical, and deterministic models to further develop the analysis on IRI values is something that holds a lot of promise in the engineering and planning industry. When roughness measurements are mixed with other parameters of transport planning, more variables and relationships can be analyzed. A sample case study in Indonesia done by Sutandi and Santosa (2013) analyzed road roughness measurements and identified accident black spots in one of Indonesia's national roads. In addition, Tsukonawa and Ul-Islam (2003) investigated optimal pavement designs for developing countries based on life cycle cost analyses given threshold road roughness criteria. Furthermore, Douangphachanh and Oneyama (2013) profiled the road roughness index across a full road segment to identify anomalies such as road bumps, potholes, and other major road disruptions that affect roughness values significantly.

In the Philippine setting, the IRI is used by the Department of Public Works and Highways (DPWH) for road development and maintenance. The IRI is used as input to the Highway Development and Management Model (HDM-4) to make strategic planning evaluations and maintenance of the national road network. Likewise, the IRI values are often used as basis for the acceptance of the road project after its completion.

Among the various methods used to measure IRI are: 1) Face Dipstick Profile: A Class 1 IRI measuring device in which the operator walks along a survey line alternately pivoting the instrument about each leg. It is recognized in road industry studies as the ideal device for establishing reference road roughness data for calibrating high speed profilometers and response-type road roughness measuring systems (Face Construction Technologies, Inc., 2014); 2) Road Measurement Data Acquisition System (ROMDAS): Another popular IRI measuring device because of the bumper integrator and reference profiles tools that allow easier mounting on the vehicle of choice (Data Collection Ltd., 2013). It is practical and easy to use since it is fully automatic and computer-operated, reducing mistakes due to human errors (Susilo et al., 2001); 3) Machine for Evaluating Roughness using Low-cost Instrumentation (MERLIN): The Transport Research Laboratory, developers of the MERLIN, claimed that it is tailored to fit the road roughness measurement requirements of developing countries (Cundill, 1996). However, since the structure of MERLIN has a very intricate and manual setup, it might not be the best technique to use in urban roads or roads with heavy traffic. Given also the new technology of GPS sensors on most gadgets, the MERLIN manual method of calculation may seem cumbersome by modern standards; and 4) Vehicle Intelligent Monitoring System (VIMS): A very popular equipment containing waterproof accelerometers, and has an accompanying logger and GPS unit. Initialization or calibration is done for each unique vehicle used for the measurements, and time synchronization between PC and the logger is ensured to facilitate accurate measurements (Tokyo Sokki System, 2012). A typical road inspection vehicle equipped with multiple sensors can cost up to several million pesos. Developing countries find this steep price to be a challenge or roadblock in the monitoring of their road networks' health.

Recent developments on road roughness measurements indicate that the common pursuit for improving the art of measuring road characteristics generally requires a lot of additional expense – which makes it more challenging to implement in developing countries. Even with the right amount of funding, more roads can be covered with the use of ubiquitous tools such as the smartphone.

This paper therefore aims to propose an alternative method to measure road roughness using smartphones and GIS for the Philippine setting. It is the aim of the authors to use similar techniques to develop innovative and alternative ways to measure road roughness without the use of expensive road inspection vehicles. In order to validate the proposed smartphone road survey methodology, the results were compared with those of the results from an official government-funded IRI survey using standard roughness measuring equipment. The paper likewise explores the proposed methodology's application to road network planning in the Philippines.

2. METHODOLOGY

2.1 Survey Methodology

The study utilized the iPhone smartphone. However, android-based smartphones equipped with accelerometer can also be considered but subject to further research. Figure 2 summarizes the survey methodology used in the study.

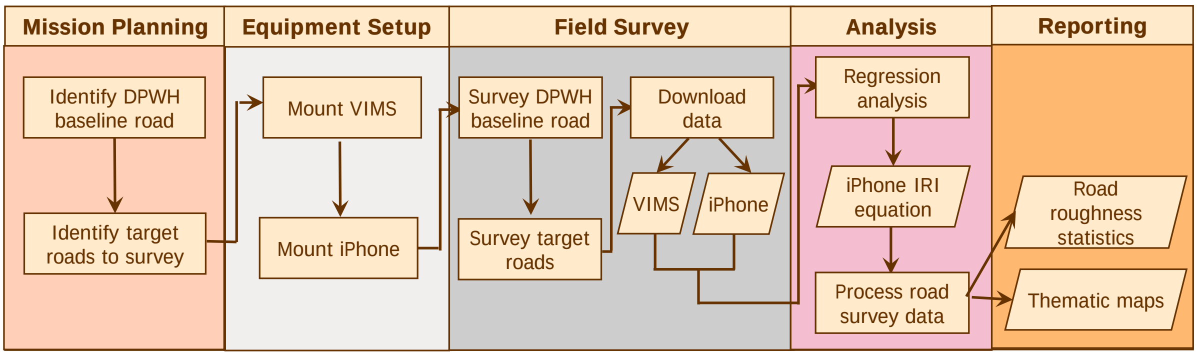


Figure 2. Study Survey Methodology

1. Mission Planning Phase
   - Identify baseline DPWH road to be used for establishing correlation of DPWH IRI and smartphone IRI values. This step was necessary to calibrate the vehicle used in the survey.
   - Identify target roads to survey using the proposed smartphone survey method. The target roads shall be used to validate the results of the smartphone survey by comparing the IRI values derived from the smartphone survey and VIMS.

2. Equipment Setup
   - Install "Sensor Data Application" on smartphone
   - Mount smartphones in vehicle (dashboard and above rear axle of the vehicle)
   - Mount VIMS equipment in vehicle

3. Field Survey Phase
   - Conduct survey of baseline road to calibrate vehicle
   - Conduct survey of target roads
   - Download data to PC

4. Analysis phase
   - Process baseline road survey data to test correlation between DPWH IRI, VIMS IRI and smartphone survey results.
   - Process baseline road survey data using regression analysis tools of Microsoft Excel to derive correlation parameters to come up with the IRI equation using the following smartphone parameters or combination of parameters:
     - DPWH IRI vs VIMS IRI
     - VIMS IRI vs Smartphone Acceleration (G) parameter
     - VIMS IRI vs Smartphone Acceleration (G) and Speed (kph) parameter combination
   - Determine the best correlation result between VIMS and IRI survey results to come up with the optimum IRI equation
   - Using the IRI equation derived from the baseline road survey, calculate the IRI values of the baseline and target roads

5. Reporting Phase
   - Using GIS Software, generate thematic maps of the baseline and target roads showing the IRI values at different sections of the roads.
   - Using Microsoft Excel, generate summary tabular reports of the IRI values of the baseline and target roads.

Figure 3 below shows the equipment setup for the road roughness survey. Two smartphones were used to gather information. One smartphone was mounted on the rear axle and another smartphone was mounted on the dashboard near the driver's seat.

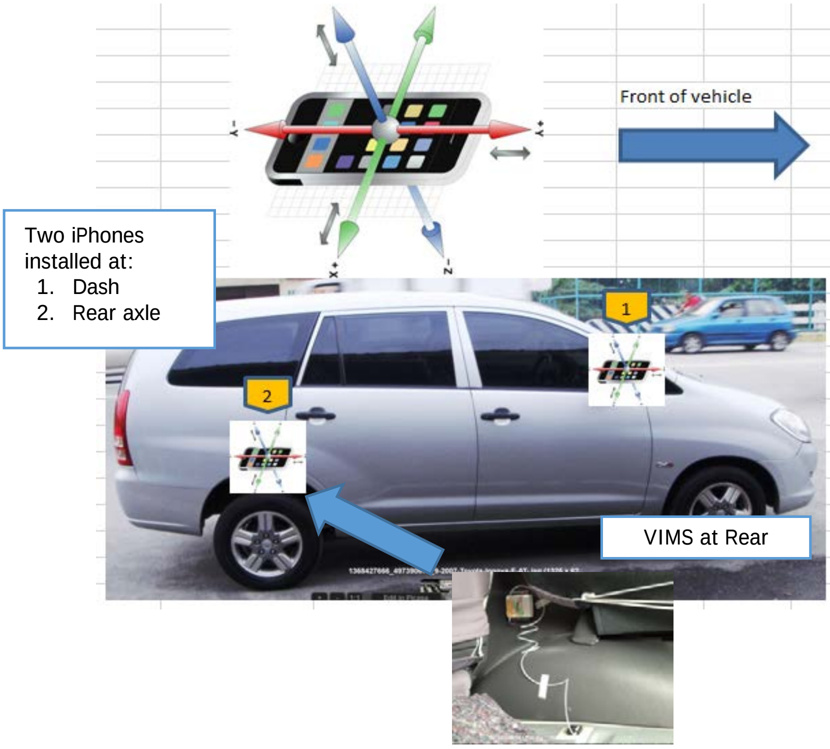


Figure 3. Road Roughness Survey Equipment Setup

Alongside the two smartphone handsets was the mounting of actual VIMS equipment to serve as baseline data source for the study outputs. The VIMS was mounted on the rear wheel axle as well. The main vehicle of choice was a Toyota Innova. There is also no particular reason why this model was selected. The methodology proposed requires calibration whenever the survey vehicle is changed or whether any modifications were made on the vehicle that may affect the riding characteristics of the vehicle such as change of tires.

The smartphone devices used were then calibrated using relevant application that allow the use of appropriate sensors for determining road roughness indices. “Sensor Data Application” by Wavefront labs, a commercial data logger app was used to log accelerometer (in x,y,z), speed and GPS readings from the iPhone to an excel csv file. The frequency was set at the appropriate amount of Hertz as seen in various trials run for successful gathering of data.

Data gathering begins as soon as the prepared smartphone devices are mounted on a convenient vehicle of choice at the starting point of the area of interest. Some of the characteristics recorded include but are not limited to the following: acceleration, pitch roll, yaw, rotation, gravitational acceleration, user acceleration, rotation rate, magnetic headings, true headings, latitude, longitude, altitude, and distance.

The purpose of placing two smartphones was to compare which placement would have a better correlation to IRI measurements made by VIMS. Unfortunately, the smartphone placed on the rear axle failed to log properly, and thus only the dash-mounted smartphone was used for the study.

2.2 Data Processing

Data were immediately backed up using a portable laptop or other computing device. Logs were stored in raw format and then later analyzed and extracted to produce a road condition file. Invalid sensor readings or those which were found to have low location accuracy when plotted on a GIS software (i.e., ArcGIS or QGIS) were eliminated. Acceleration (G) values were re-arranged into intervals of 10 meters for both VIMS and smartphone results to align the segments accordingly. Midpoint coordinates of latitude and longitude using WGS84 system were used to create the point data. World Geodetic System (WGS) is a standard for use in cartography, geodesy, and navigation and it comprises a standard coordinate system for the Earth, a standard spheroidal reference surface (the datum or reference ellipsoid) for raw altitude data, and a gravitational equipotential surface (the geoid) that defines the nominal sea level. This series of points were processed into a single line. Road codes and directions of the route were assigned accordingly once it has become a line segment on a map. These shapefiles then become the main files of analysis for processing, establishing relationships between IRI values of VIMS and IRI values of smartphone surveys, and devising a repeatable formula that were later tested in other study areas.

Based on this consolidated road condition file, various forms of outputs can be created such as tables, maps, and database. From the survey data file format shown below (Table 1), regression analyses were then performed.

Table 1. Sample of Survey Data File Format for Analysis

		DPWH	DPWH	DPWH	VIMS	VIMS	VIMS	iPhone	iPhone	iPhone	iPhone
StaStart	StaEnd	IRI_DPWH	Condition_DPWH	Length_DPWH	IRI_VIMS	SpeedVIMS	Length_VIMS	Speed_iP_Kph	G_iPhone	Length_iP	IRI_iPhone
0	100	3.94	Fair	100	4.23	46.27	110.00	46.30	0.08	109.89	5.27
100	200	2.95	Good	100	4.15	46.76	99.99	46.78	0.08	99.98	5.25
200	300	3.93	Fair	100	4.51	49.73	99.99	50.00	0.09	99.86	5.04

From these, the relationship between the VIMS values and DPWH-provided values were analyzed in comparison with the results found from the smartphone survey data. This smartphone result generated a working formula or correlation of IRI from smartphone survey with respect to the more reliable and widely accepted VIMS IRI values.

The merging of qualitative and quantitative information served as a guide in producing results that accurately depict the suitability of using smartphones as an alternative method of measuring IRI index values in a given road segment.

2.3 Data Analysis

Statistical regression analysis and spatial analysis in GIS were incorporated in the study to process the raw data collected from logs of the smartphone surveys and the VIMS equipment. In the case of the VIMS equipment, the appropriate accompanying software was used as well.

Three types of data were analyzed. The primary source came from the smartphone and the VIMS surveys, while the data gathered from the DPWH, the official bearer of accurate road records in the Philippines, served as referenced data.

Roughness measurements were averaged at 10, 100 and 200 meter intervals, with a proper line overlay of the three data sources mentioned above. The data was non-uniform and required pre-processing to match the appropriate road segments to be compared as described in the previous section. From the Excel or tabular format of the original data, a shapefile was generated to facilitate better spatial analysis.

The crucial part of this whole analysis involved the matching of the correct data segments from each type of output from different data sources. This way, the portions of the long road segments were properly identified from the smartphone and VIMS measurement and were correctly compared with each other. Using GIS software, this matching involved both tabular and visual format to aid in the analysis.

Using correlation analysis based on smartphone survey speed and acceleration, IRI was computed for the road segments with complete data. This was checked alongside the official data from DPWH and the VIMS survey.

3. RESULTS AND ANALYSIS

3.1 Description of Surveyed Roads

The baseline road selected for the study is a 10.2 km section along Bocaue-San Jose Road approximately starting from DPWH Location Reference Point (LRP) Km 29 up to Km 39 (Figure 4). The DPWH Planning Service Statistics Division provided the IRI survey results of the baseline road conducted in January 2013 under the World Bank funded project called “Second National Road Improvement and Management Program (NRIMP-2) Goods and Services for Pavement Data Collection Services (G-02)”.

The baseline road was used to compare the results of the VIMS and the smartphone-based road roughness survey proposed by this study in order to come up with a smartphone IRI equation. If strong correlation between the results of the DPWH, VIMS and smartphone IRI surveys for the baseline road is established, DPWH roads with existing updated IRI survey measurements may be used as baseline roads to calibrate the smartphone survey methodology in the future. There will be no need to have another standard IRI measuring equipment to calibrate the smartphone roughness survey.

Several target roads were selected in order to validate the results of the smartphone roughness survey method proposed by the study. The smartphone IRI equation derived using the baseline road was applied to the target roads. Correlations between the VIMS and smartphone IRI measurements were then determined for each target road to see how the smartphone IRI results compare with the VIMS IRI results under different road types.

Three sets of data results were analyzed: 1) DPWH data, 2) VIMS data after processing, and 3) smartphone dashboard data. A total of five days of data gathering were performed mostly during the weekends and between the hours of 12 AM to 7 AM in the early morning. The reason for the early hours was to avoid traffic along the survey routes.

Figure 4. Location of Baseline and Target Roads

3.2 Analysis of Survey Data

The regression analysis consisted of three types:

- DPWH IRI vs VIMS IRI of Baseline Road
- VIMS IRI vs Smartphone Data of Baseline Road
- VIMS IRI vs Smartphone IRI of Target Roads

3.2.1 DPWH IRI vs VIMS IRI of Baseline Road

To test the correlation between DPWH and VIMS data, regression analysis was performed. Table 2 below shows the results of the regression analysis. A high correlation coefficient of 0.643 was achieved. At the same time, the significance level is more than 95% indicating a high confidence level in the result of regression analysis. With these values, it can be concluded that

DPWH IRI survey is significantly matched by the VIMS IRI survey. The implication of this is that if the smartphone survey can match the results of the VIMS survey, the DPWH baseline roads where IRI survey has been conducted before can be used in the future to calibrate the smartphone survey to come up with accurate IRI values. There will be no need to use VIMS equipment to calibrate smartphone surveys.

Table 2. Correlation Coefficient (R) for DPWH IRI vs VIMS IRI of Baseline Road

	DPWH IRI vs VIMS IRI
Correlation Coefficient (R) @ 100m interval	0.643

3.2.2 VIMS IRI vs Smartphone Sensor Data of Baseline Road (using Smartphone Acceleration (G) only)

Regression analysis between VIMS IRI survey of the baseline road vs the smartphone acceleration (G) readings resulted in a correlation coefficient of 0.62. An equation was then formulated to calculate IRI as shown below:

$$IRI = 26.04 \times Acceleration + 2.614 \quad (1)$$

Equation 1 was formulated by using coefficients derived from the regression analysis of VIMS and smartphone survey results.

3.2.3 VIMS IRI vs Smartphone Sensor Data of Baseline Road (using smartphone Acceleration (G) + Speed)

Regression analysis between VIMS IRI survey of the baseline road versus the smartphone acceleration (G) plus speed readings resulted in a much higher correlation coefficient of 0.75. This indicates that when acceleration in combination with the speed sensor of the smartphone is used, a more accurate equation can be formulated to calculate IRI. The IRI equation is shown by Equation 2.

$$IRI = 22.56 \times Acceleration - 0.11 \times Speed + 8.71 \quad (2)$$

Equation 2 was formulated by using coefficients derived from the regression analysis of VIMS and smartphone survey results. This equation can now be applied to target roads surveyed in order to validate the proposed Smartphone Road Roughness Survey method proposed by this paper.

3.2.4 VIMS IRI vs Smartphone IRI of Target Roads

Using Equation 2, IRI values were calculated for the target roads surveyed. Table 3 summarizes the results of the regression analyses conducted between VIMS IRI vs smartphone IRI survey.

Table 4 summarizes the conditions during the baseline and target roads survey. By considering the results of the regression analyses and the road conditions of the target road surveys, the conditions where higher accuracies using the proposed smartphone survey method were achieved can be identified.

Table 3. Summary of Regression Analysis Results of Target Roads

No.	Road Section	Total Length (m)	R at 10m intervals	R at 100m intervals	R at 200m intervals
1	Commonwealth Ave_Outbound_208	11,840	0.186	0.291	0.324
2	Quirino Highway_Outbound_228	6,840	0.480	0.701	0.761
3	Muzon-TungkongMangaRd East_Outbound_228	1,440	0.306	0.640	0.790
4	Muzon-TungkongMangaRd West_Outbound_228	2,450	0.474	0.721	0.810
5	Bocaue-SnJoseRd_Outbound_228	3,350	0.441	0.613	0.745
6	Bocaue-SnJoseRd_Outbound_248	500	0.492	0.897	0.958
7	Bocaue-SnJoseRd_Outbound_249	5,940	0.080	0.148	0.226
8	Bocaue-SnJoseRd_Inbound_301 (DPWH base data)	10,860	0.561	0.742	0.794
9	Muzon-TungkongMangaRd West_Inbound_301	2,560	0.387	0.490	0.691
10	Muzon-TungkongMangaRd East_Inbound_301	1,470	0.161	0.122	0.095
11	Quirino Highway_Inbound_321	6,680	0.312	0.410	0.610
12	Commonwealth Ave_Inbound_321	6,160	0.343	0.451	0.574
13	Commonwealth Ave_Inbound_341	5,130	0.294	0.475	0.510
14	Quezon Ave_Inbound_341	720	0.342	0.490	0.587
15	EDSA North_Inbound_341	2,420	0.060	0.153	0.348
16	Aurora Blvd West_Inbound_401	3,210	0.199	0.202	0.365
17	Aurora Blvd West_Outbound_401	3,050	0.008	0.145	0.114
18	EDSA South_Inbound_421	4,840	0.132	0.158	0.224
19	EDSA South_Outbound_421	5,000	0.087	0.105	0.095
20	EDSA North_Outbound_421	830	0.048	0.381	0.634
21	EDSA North_Outbound_441	720	0.196	0.182	0.271
	Grand Total	86,010			

Note: Inbound Direction refers to the direction going towards the Rizal Monument in Luneta Park (Km 0).

Table 4. Summary of Survey Conditions of Baseline and Target Roads

No.	Road Section	Wea-ther	Traffic	Horizontal Obstruc-tion	Vertical Obstruc-tion	Land Use	Remarks	Pavement
1	Commonwealth Ave_Outbound_208	Dry	Med	Med	Light	Com	Traffic	Concrete
2	Quirino Highway_Outbound_228	Dry	Light	Light	Light	Com	-	Concrete
3	Muzon-Tungkong Manga Rd East_Outbound_228	Dry	Light	Light	Light	Res	-	Asphalt
4	Muzon-Tungkong Manga Rd West_Outbound_228	Dry	Light	Light	Light	Res	-	Asphalt
5	Bocaue-SnJoseRd_Outbound_228	Dry	Light	Light	Light	Res	-	Asphalt
6	Bocaue-SnJoseRd_Outbound_248	Dry	Med	Med	Light	Res	-	Asphalt
7	Bocaue-SnJoseRd_Outbound_249	Dry	Med	Med	Light	Res	-	Asphalt
8	Bocaue-SnJoseRd_Inbound_301 (DPWH base data)	Dry	Light	Light	Light	Res	-	Asphalt
9	Muzon-Tungkong Manga Rd West_Inbound_301	Dry	Light	Light	Light	Res	-	Asphalt
10	Muzon-Tungkong Manga Rd East_Inbound_301	Dry	Med	Med	Light	Res	-	Asphalt
11	Quirino Highway_Inbound_321	Dry	Light	Light	Light	Com	-	Concrete
12	Commonwealth Ave_Inbound_321	Dry	Med	Med	Light	Com	Traffic	Concrete
13	Commonwealth Ave_Inbound_341	Dry	Med	Med	Light	Com	Traffic	Concrete
14	Quezon Ave_Inbound_341	Dry	Med	Med	Med	Com	Traffic	Asphalt
15	EDSA North_Inbound_341	Dry	Med	Med	Med	Com	GPS/MRT	Concrete
16	Aurora Blvd West_Inbound_401	Dry	Med	Med	Heavy	Com	GPS/LRT	Concrete
17	Aurora Blvd West_Outbound_401	Dry	Med	Med	Heavy	Com	GPS/LRT	Concrete
18	EDSA South_Inbound_421	Dry	Med	Med	Med	Com	Traffic	Concrete
19	EDSA South_Outbound_421	Dry	Med	Med	Med	Com	Traffic	Concrete
20	EDSA North_Outbound_421	Dry	Med	Med	Med	Com	Traffic	Concrete
21	EDSA North_Outbound_441	Dry	Med	Med	Med	Com	Traffic	Concrete

Legend: Res: Residential Com: Commercial Med: Medium

Table 5 provides the average IRI by road segment using VIMS and the proposed smartphone survey method.

Table 5. Average IRI by Road Segment

No.	Road Section	VIMS Results	Smartphone Results
		Average IRI	Average IRI
1	Commonwealth Ave_Outbound_208	4.5	5.32
2	Quirino Highway_Outbound_228	4.82	4.92
3	Muzon-Tungkong Manga Rd East_Outbound_228	6.22	5.94
4	Muzon-Tungkong Manga Rd West_Outbound_228	4.85	4.8
5	Bocaue-SnJoseRd_Outbound_228	4.18	4.14
6	Bocaue-SnJoseRd_Outbound_248	4.91	4.74
7	Bocaue-SnJoseRd_Outbound_249	4.94	5.23
8	Bocaue-SnJoseRd_Inbound_301 (DPWH base data)	4.89	4.89
9	Muzon-Tungkong Manga Rd West_Inbound_301	5.3	4.9
10	Muzon-Tungkong Manga Rd East_Inbound_301	6.27	5.8
11	Quirino Highway_Inbound_321	5.09	5
12	Commonwealth Ave_Inbound_321	4.31	4.68
13	Commonwealth Ave_Inbound_341	4.25	4.12
14	Quezon Ave_Inbound_341	4.3	5.75
15	EDSA North_Inbound_341	5.56	6.57
16	Aurora Blvd West_Inbound_401	4.94	5.03
17	Aurora Blvd West_Outbound_401	4.79	5.45
18	EDSA South_Inbound_421	4.61	5.03
19	EDSA South_Outbound_421	4.08	5.1
20	EDSA North_Outbound_421	4.93	5.79
21	EDSA North_Outbound_441	4.31	6.66

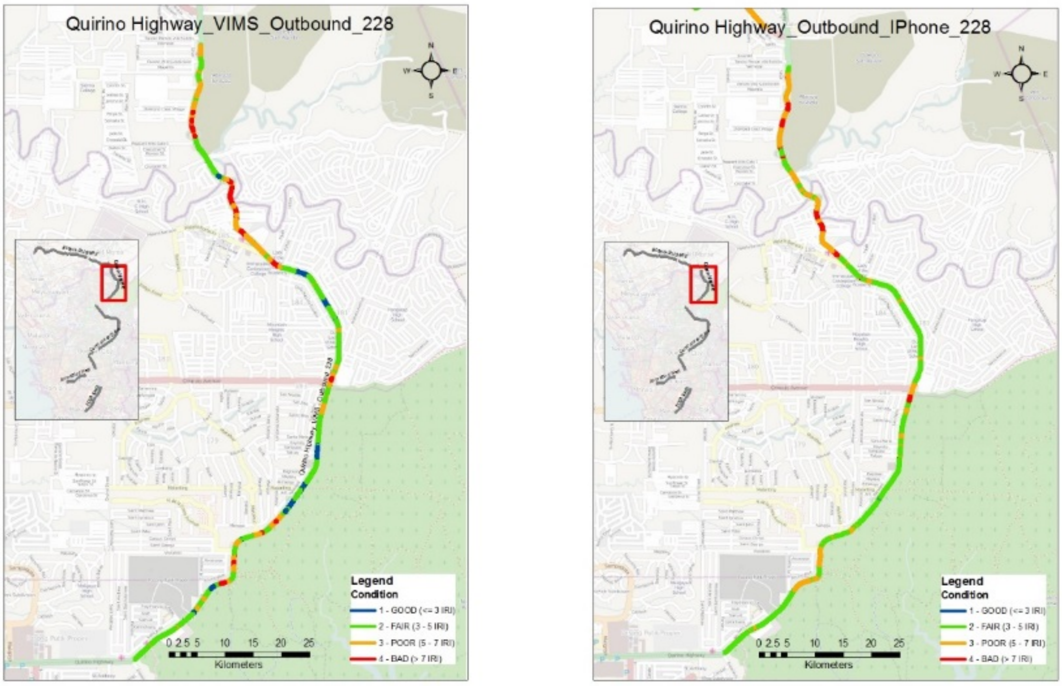
Although DPWH vs VIMS IRI survey results have a high correlation, differences between the results can be expected. The differences in IRI results was due to several factors:

- The date of survey for the DPWH IRI was January 2013 while that of the VIMS survey was November 2013. There is a 10-month difference. In that period, deterioration of the pavement most probably has occurred.
- GPS accuracy differences during the dates of survey. When comparing IRI, the location of the segments being compared has a bearing on correlation therefore causing the differences in IRI values between the DPWH and VIMS surveys.

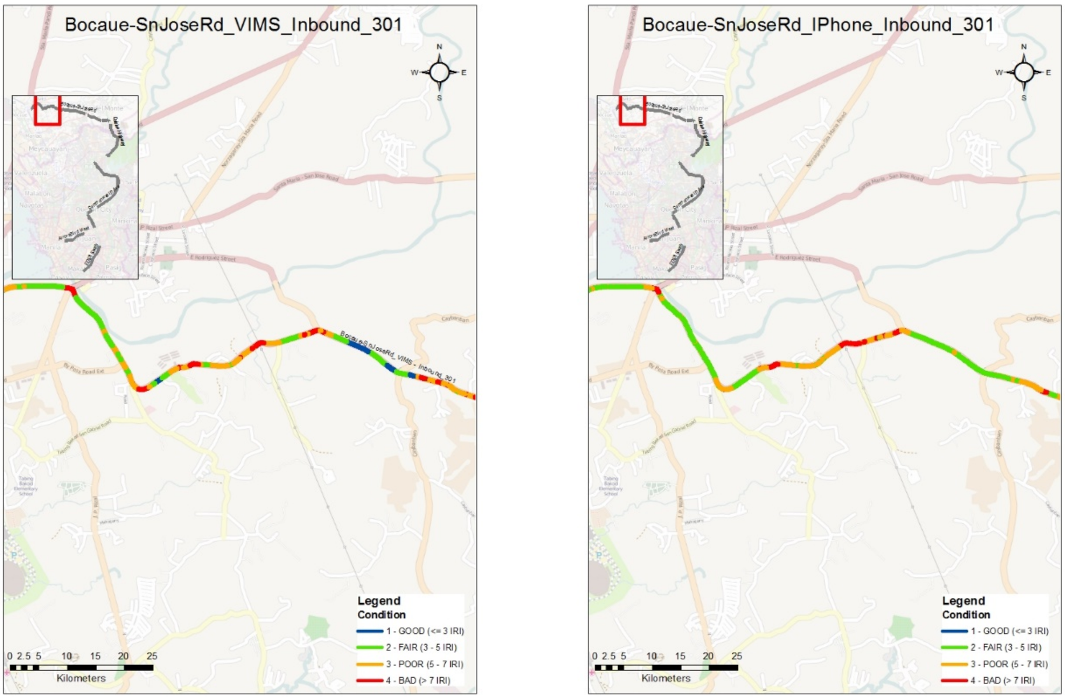
The following observations can be made based on the results of the road roughness survey:

- Higher IRI accuracies can be achieved in low traffic conditions, where constant speeds can be maintained.
- The smartphone IRI survey method is highly dependent on GPS accuracy. Vertical obstructions such as buildings and overhead railways (e.g., LRT, pedestrian walkways, etc.) that can obscure clear line of sight to overhead navigation satellites should be avoided. The implication of this is that the smartphone survey method is more effective in national roads outside the urban area and arterial roads within the urban area without much vertical obstructions.
- Weather should also be considered when conducting IRI survey since weather conditions affect GPS accuracies. Dry weather conditions are most ideal.

Figures 5a and 5b show a sample map of the IRI values for the VIMS and proposed smartphone surveys using the Good, Fair, Poor and Bad classification of DPWH.



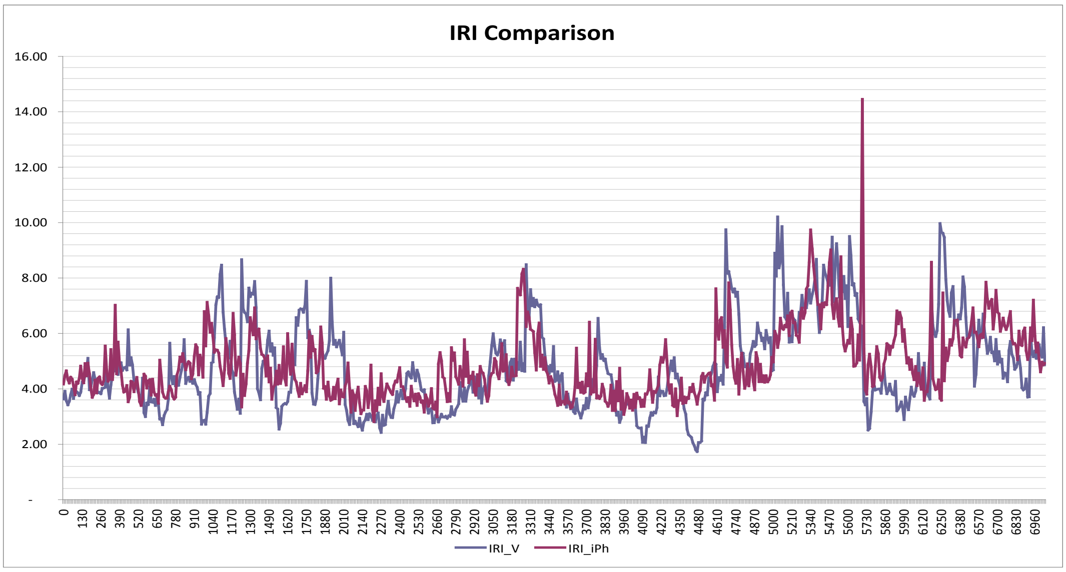
a) Quirino Highway_Outbound_228 Road Section



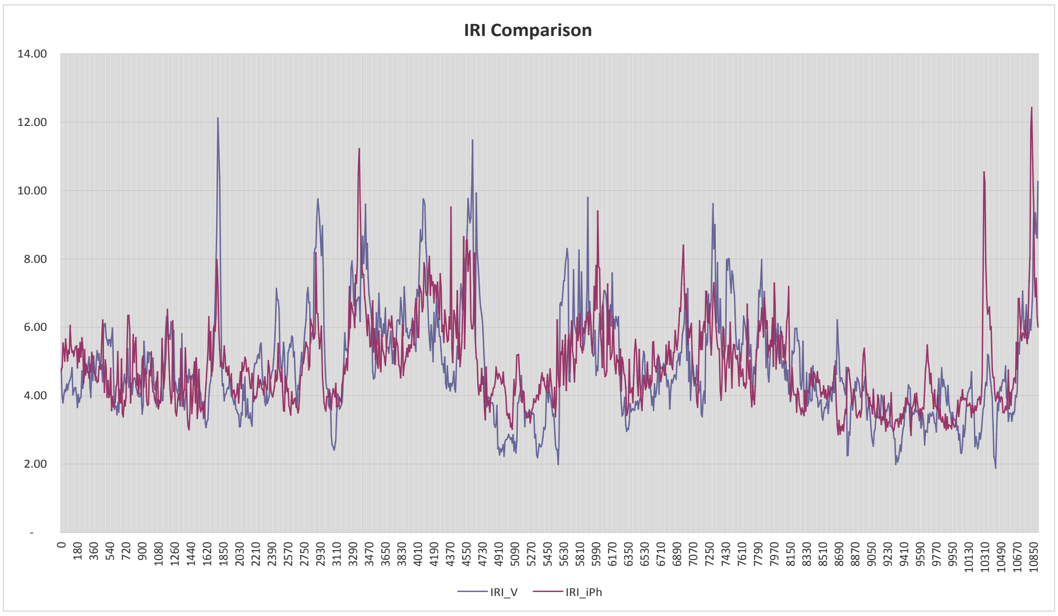
b) Bocaue-Sn JoseRd_Inbound_301 Road Section (DPWH Base Data)

Figure 5. Sample Maps of VIMS vs Smartphone IRI Classification

Figures 6a and 6b show the IRI comparison between the VIMS and proposed smartphone survey along a sample target road and the base road. The two sets of IRI values are by and large very close and generally follow the same trend for the two road sections. However, there are instances that the calculated smartphone IRI are noticeably off than the VIMS IRI. This may be due to reasons previously discussed in Sec. 3.2.4. Nevertheless, the proposed smartphone survey results can be described as comparable with the VIMS survey results.



a) Quirino Highway_Outbound_228 Road Section



b) Bocaue-Sn JoseRd_Inbound_301 Road Section (DPWH Base Data)

Figure 6. Sample Line Graph of VIMS vs Smartphone IRI Values

4. APPLICATION TO ROAD NETWORK PLANNING IN THE PHILIPPINES

Given the capability of the smartphone to match the results of traditional IRI equipment, the proposed road roughness methodology can be incorporated to road network planning in the Philippines. The developed methodology may be used by the Planning Services Department of the DPWH and/or the Local Government Units (LGUs) responsible for maintaining Philippine roads.

Presently, the DPWH uses HDM-4 as a tool to maintain its national roads. The extensive research and continuous improvement of the Highway Development and Management makes it a contending standard for national road planning and maintenance. Apart from the comprehensive manuals provided by the World Bank for HDM-4, supplementary software and databases are also provided that reinforce its use globally. The DPWH Planning Services Department is well-experienced in the use of the HDM-4 tool, in which a major input is the information on road roughness of road segments. If road roughness information can be collected straightforwardly using simplified road roughness methodology employing smartphones, then highway maintenance parameters which rely heavily on corrections accounting for a road segment's roughness values, can be easily modeled thereby facilitating road asset preservation and maintenance activities.

The combination of spatial, statistic, and mobile tools contribute to a robust, dynamic, and easy to maintain system that can be of benefit to transport planners and engineers. When the sensor data are continuously tied to a road management system, the outputs can answer questions ranging from relevant issues in transport including policy improvements, information dissemination, road user transport guidance, and even globally pervading issues like climate change.

5. CONCLUSION

The paper proposed an alternative methodology to measure road roughness using ubiquitous and inexpensive smartphones to determine road conditions at case study roads. It was able to prove that the proposed smartphone road roughness survey method can be a viable substitute to traditional IRI survey methods.

The survey compiled roughness measurements along the case study roads using Vehicle Intelligent Management System (VIMS) and the proposed smartphone road roughness method. These data were the basis in coming up with an IRI equation. The smartphone road roughness method has proven that the smartphone has a viable accelerometer inside that can be correlated to traditional equipment for measuring road roughness such as the VIMS equipment. A linear correlation can be observed between VIMS baseline data and smartphone survey data with parameters of acceleration and speed.

Linear regression results showed that it is best to take into account both speed and acceleration for the formula of getting IRI from the smartphone survey. Significant correlation coefficients between VIMS equipment and smartphone method were achieved for certain roads satisfying the conditions required to achieve accurate IRI survey using smartphones.

Given the capability of the smartphone to match the results of traditional IRI equipment, the proposed smartphone road roughness methodology may be applied to road network evaluation and maintenance. The developed methodology may be used by the DPWH to evaluate national roads, and by the Local Government Units (LGUs) to assess provincial, municipal, urban and local (i.e., barangay) roads.

The smartphone survey method though has some limitations. The accuracy of the results of the smartphone road roughness survey method is highly dependent on GPS and speed readings. Experience during the conduct of trial surveys to test the smartphone survey method showed that the method is best used in road sections where constant speeds can be maintained, such as in low traffic roads. In addition, vertical obstructions commonly found in the urban setting such as buildings and elevated railways likewise tend to degrade GPS accuracies.

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