

Developing a Low-cost Road Roughness Survey Methodology using Smartphones and Geographic Information System (GIS)

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Abstract: An important indicator of road condition is the measure of its roughness. The World Bank (WB) established the International Road Roughness Index (IRI) as a standard to measure road roughness. Although many types of road inspection vehicles can measure IRI, a typical road inspection vehicle equipped with multiple sensors can cost up to several millions of pesos. Developing countries find this steep price to be a challenge for the monitoring of their road networks. Therefore, this paper aims to propose an alternative method to measure roughness using smartphones and Geographic Information System (GIS) for the Philippine setting. The proposed methodology will be based on data collected by smartphones which will then be processed using GIS to come up with approximate road roughness measurements. The results of the proposed methodology will be compared with the existing IRI standard established by the World Bank to measure road roughness of different types of roads. In addition, the paper will try to look into the developed methodology's application and integration to road network planning in the Philippines.

Key words: Road roughness index, Smartphone, GIS, Road network planning

1. INTRODUCTION

The road network is one of the most essential types of infrastructure that links our regions. It allows the efficient movement of people and goods and promotes economic growth. To ensure smooth movement of people and goods, the road network needs to be maintained. In order to facilitate road maintenance activities, road pavement condition inspections are needed to be performed regularly. Various studies and economic models have attested to the value of road network as a very good way to promote development of a country or an area. On a wider scale, institutions like the World Bank even have good estimates of how much infrastructure can affect the GDP of a nation and stated that "recent research shows that every 10 percent increase in infrastructure provision increases output by approximately 1 percent in the long term" (World Bank, 2013).

An important indicator of road condition is the measure of its roughness. The World Bank (WB) established a standard to measure road roughness called International Road Roughness Index (IRI). Previously, there were various instruments used to estimate roughness but it was hindered by "a large number of factors that cause variations between readings of similar instruments and even for the same instrument" (World Bank, 1986). Because of these differences and issues in calibration, the International Road Roughness Experiment (IRRE) in Brazil addressed this issue in 1982, and was later developed as a World Bank technical paper which became a very viable standard in ascertaining road roughness.

Many types of road inspection vehicles can measure IRI. A typical road inspection vehicle equipped with multiple sensors can cost up to one million US dollars. Developing countries find this steep expense to be a challenge or roadblock in the monitoring of their road networks' health. Therefore, this paper 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 of the survey will be compared with those of the results from the IRI survey using standard roughness measuring equipment. An iPhone 4S will be used to test this on major roads in Metro Manila and parts of Bulacan.

2. REVIEW OF RELATED LITERATURE

Among the various methods used to measure road roughness are described below:

Face Dipstick Profile: The Face Dipstick Profiler is a Class 1 IRI measuring device that is used in various countries by clients including the World Bank, the World Road Association, and the United States Federal Highway Administration (FHWA). To operate the Dipstick Profiler, the operator walks along a survey line alternately pivoting the instrument about each leg. Two digital displays show the elevation difference between the Dipstick's two support legs. Audible and visual signals alert the operator when each elevation difference reading is measured and automatically recorded. The Dipstick 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).

Vehicle Intelligent Monitoring System (VIMS): VIMS is a very popular equipment type for measuring IRI values. A brainchild of Japanese researchers in University of Tokyo, VIMS has accelerometers that are waterproof and placed on the axle. It also 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, and there is also a procedure for balancing the sensor to prevent drift (Tokyo Sokki System, 2012). During analysis, hump and speed calibrations are done depending on the type of vehicle. Comprehensive support to getting IRI estimations from hump and speed calibration procedure is available for VIMS.

VIMS for iPhone: JIP Technoscience recently developed a system to assess road roughness using an iPhone placed on the dashboard of the car which then shows road roughness values. The system is called "VIMS" or Vehicle Intelligent Monitoring System, which is an app to measure the roughness of roads in three-dimensions using a built-in sensor. This system can also record the location information and video during driving. Based on the IRI, the level of roughness can be determined by category. When combined with other map software, the road conditions can be easily seen and facilitate identification of maintenance priorities (Nihon Keizai Shinbun, 2013).

Road Measurement Data Acquisition System (ROMDAS): Road Measurement Data Acquisition System (ROMDAS) is another device that is known for generating IRI values. It is popular because of the bumper integrator and reference profiles tools that allow an easier mounting of the measuring device on the vehicle of choice (Data Collection Ltd., 2013). ROMDAS has been considered more practical and fast in use since it is fully automatic and computer-operated, which reduces some mistakes due to human errors, and can also be used in every weather condition (Susilo et al., 2001).

Machine for Evaluating Roughness using Low-cost Instrumentation (MERLIN): The Transport Research Laboratory, creators of the MERLIN, claimed that it is tailored to fit the road roughness measurement requirements of developing countries (Cundill, 1996). It has a standard equation for IRI which is linked to what is termed as the Merlin chart in units of millimeter. Since repetition is key, the stringency of MERLIN lies in strictly exacting the increments so that the measurement calculations will produce the right IRI values. Since the structure of MERLIN itself has a very intricate and manual setup, it might not be the best technique to use in urban roads or roads with heavy traffic. Open areas are more suitable. Given also the new technology of GPS sensors on most gadgets, the MERLIN manual method of calculation may seem cumbersome by modern standards.

3. METHODOLOGY

3.1 Survey Methodology

Both qualitative and quantitative methods were used in the study. This was selected to reflect both the numerical and non-numerical aspects that surround road roughness measurement. Qualitative method includes armchair research from relevant studies. Apart from this, the Department of Public Works and Highways (DPWH), a central authority in Philippine road maintenance, served as a crucial source of local information through Key Informant Interviews (KII). Specifically, policy makers and technical experts in the government were asked to answer questions on certain issues related to road network planning in the Philippines, manuals or standards in Philippine road network planning, road pavement inspection procedures, and existing applications used to monitor roads, among others.

For the quantitative method, the following summarizes the survey methodology used in the study (Figure 1).

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 survey.
 - Identify target roads to survey using the smartphone survey method proposed by this study. 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.

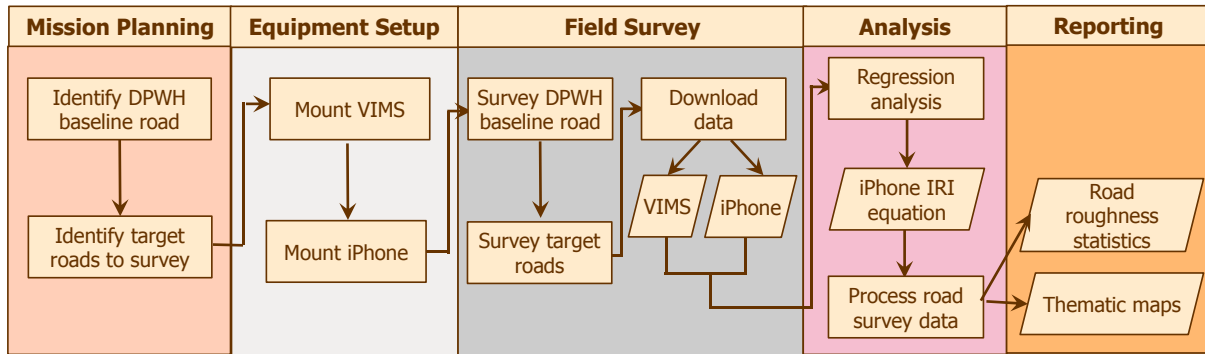


Figure 1. Survey Methodology

Two smartphones were used as main handsets for gathering information. One smartphone was mounted on the rear axle and another smartphone was mounted on the dashboard near the driver's seat. The frequency was set at the appropriate amount of Hertz as seen in various trials run for successful gathering of data.

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 the Toyota Innova.

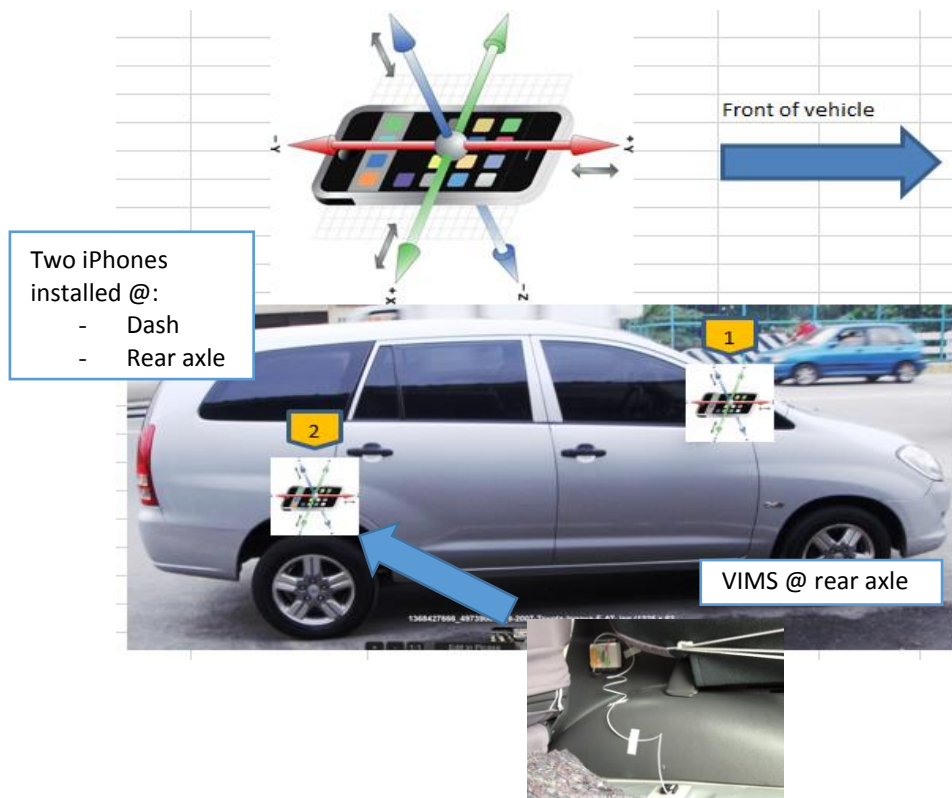


Figure 2. Road Roughness Survey Equipment Setup

The smartphone devices used were then calibrated using relevant apps that allow the use of appropriate sensors for determining road roughness indices. 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.

This data was 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 Z 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 WGS 84 system were used to create the point data. 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 analysis was then performed.

Table 1. Sample of Survey Data File Format for Analysis

		DPWH			VIMS			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.

3.2 Data Processing and 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

was properly identified from the smartphone and VIMS measurement and was 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 vis-a-vis the official data from DPWH and the VIMS survey.

4. RESULTS AND ANALYSIS

4.1 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. 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 smartphone survey methodology in the future. There will be no need to have another standard IRI measuring equipment to calibrate the smartphone roughness survey.

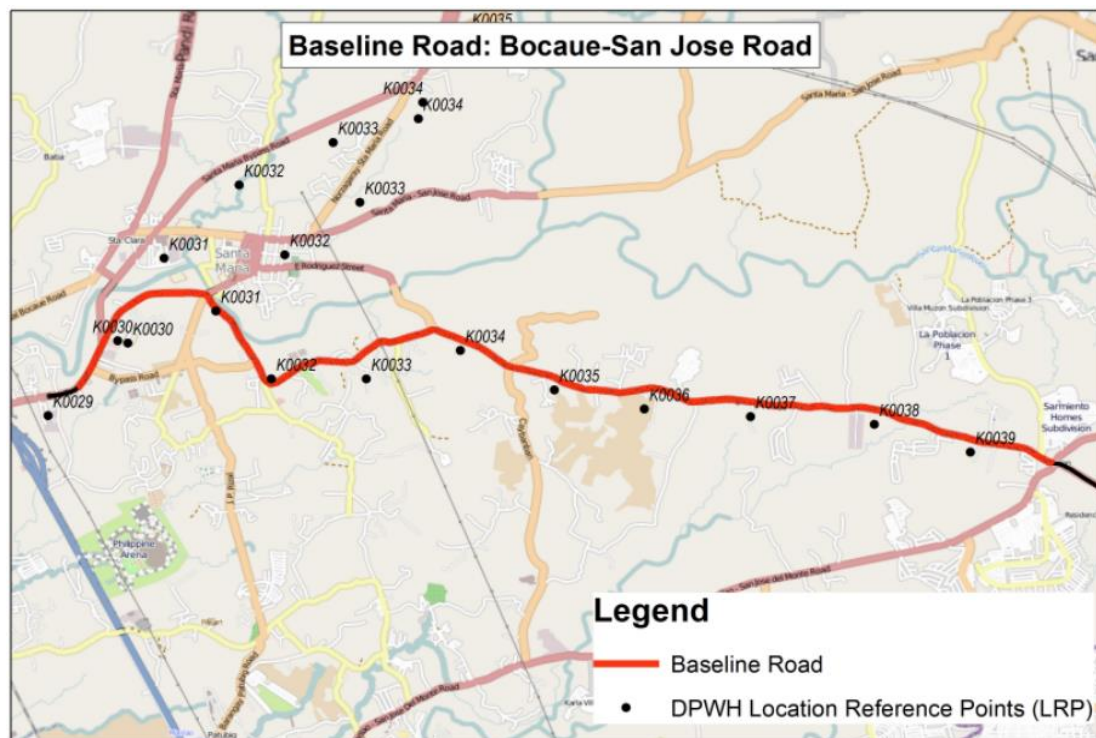


Figure 3. Location of the Baseline Road: Bocaue-San Jose Road

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. The target roads selected for the study were:

- Muzon-Tungkong Manga Road
- Quirino Avenue
- Commonwealth Avenue
- Quezon Avenue
- EDSA North
- Aurora Blvd
- EDSA South



Figure 4. Map of Target Roads

Three sets of data results were analyzed: a) VIMS data after processing, b) smartphone dashboard data, and c) DPWH 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.

4.2 Analysis of Survey Data

The regression analysis consisted of three types:

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

4.2.1 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 factor is much less than 5% 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. Although DPWH vs VIMS IRI survey results have a high correlation, differences between the results can be expected. The differences in IRI results may be 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.

Table 2. Correlation Coefficient Results for DPWH IRI vs VIMS IRI of Baseline Road

Test	DPWH IRI vs VIMS IRI
Correlation Coefficient @ 100 m interval	0.643

4.2.2 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.

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

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

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

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.

4.2.4 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 3. Summary of Regression Analysis Results of Target Roads

No.	Road Section	Total Length(m)	R at 10m intervals	R at 100 m 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			

Notes:

1. Inbound Direction of a road as used in this paper refers to the direction of road going towards the Rizal Monument in Luneta Park which is also the location on DPWH LRP Km 0. Outbound direction refers to the direction going away from Km 0.

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 are achieved can be identified.

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

No .	Road Section	Weather	Traffic	Horizontal Obstruction	Vertical Obstruction	Land Use	Remarks	Pave ment
1	Commonwealth Ave_Outbound_208	Dry	Moderate	Mod	Yes	Com	Traffic	Concrete
2	Quirino Highway_Outbound_228	Dry	Light	Light	Yes	Com		Concrete
3	Muzon-Tungkong Manga Rd East_Outbound_228	Dry	Light	Light	Yes	Res		
4	Muzon-Tungkong Manga Rd West_Outbound_228	Dry	Light	Light	Yes	Res		
5	Bocaue-SnJoseRd_Outbound_228	Dry	Light	Light	Yes	Res		Asphalt
6	Bocaue-SnJoseRd_Outbound_248	Dry	Moderate	Mod	Light	Res		Asphalt
7	Bocaue-SnJoseRd_Outbound_249	Dry	Moderate	Mod	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	Moderate	Mod	Light	Res		Asphalt
11	Quirino Highway_Inbound_321	Dry	Light	Light	Light	Com		Concrete
12	Commonwealth Ave_Inbound_321	Dry	Moderate	Mod	Light	Com	Traffic	Concrete
13	Commonwealth Ave_Inbound_341	Dry	Moderate	Mod	Light	Com	Traffic	Concrete
14	Quezon Ave_Inbound_341	Dry	Moderate	Mod	Mod	Com	Traffic	Asphalt
15	EDSA North_Inbound_341	Dry	Moderate	Mod	Mod	Com	GPS/MRT	Concrete
16	Aurora Blvd West_Inbound_401	Dry	Moderate	Mod	Heavy	Com	GPS/LRT	Concrete
17	Aurora Blvd West_Outbound_401	Dry	Moderate	Mod	Heavy	Com	GPS/LRT	Concrete
18	EDSA South_Inbound_421	Dry	Moderate	Mod	Mod	Com	Traffic	Concrete
19	EDSA South_Outbound_421	Dry	Moderate	Mod	Mod	Com	Traffic	Concrete
20	EDSA North_Outbound_421	Dry	Moderate	Mod	Mod	Com	Traffic	Concrete
21	EDSA North_Outbound_441	Dry	Moderate	Mod	Mod	Com	Traffic	Concrete

Based on the results of the surveys, the following conclusions can be made when using the smartphone method of 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.

Table 5 provides side-by-side summary results of the roughness surveys using VIMS and the proposed smartphone survey methods.

Table 5. Roughness Judgment by Road Segment

No	Road Section	VIMS Results					Smartphone Results				
		Good (<= 3 IRI)	Fair (3 - 5 IRI)	Poor (5 - 7 IRI)	Bad (> 7 IRI)	Grand Total (m)	Good (<= 3 IRI)	Fair (3 - 5 IRI)	Poor (5 - 7 IRI)	Bad (> 7 IRI)	Grand Total (m)
1	Commonwealth Ave_Outbound_208	1,630	6,830	2,690	790	11,940	10	4,910	6,220	810	11,950
2	Quirino Highway_Outbound_228	640	3,720	1,850	830	7,040	20	4,330	2,210	500	7,060
3	Muzon-Tungkong Manga Rd East_Outbound_228		360	640	480	1,480		290	960	230	1,480
4	Muzon-Tungkong Manga Rd West_Outbound_228	150	1,240	1,070	90	2,550	10	1,580	950	60	2,600
5	Bocaue-SnJoseRd_Outbound_228	440	2,200	660	60	3,360	340	2,400	590	30	3,360
6	Bocaue-SnJoseRd_Outbound_248		320	180		500		310	190		500
7	Bocaue-SnJoseRd_Outbound_249	600	3,030	2,280	580	6,490		3,310	2,670	500	6,480
8	Bocaue-SnJoseRd_Inbound_301 (DPWH base data)	860	5,770	3,230	1,050	10,910	90	6,610	3,510	710	10,920
9	Muzon-Tungkong Manga Rd West_Inbound_301		1,230	1,120	220	2,570	10	1,360	1,170	20	2,560
10	Muzon-Tungkong Manga Rd East_Inbound_301		340	680	460	1,480		300	1,050	120	1,470
11	Quirino Highway_Inbound_321	330	3,550	2,110	1,070	7,060	250	3,720	2,410	680	7,060
12	Commonwealth Ave_Inbound_321	1,480	2,980	1,740	350	6,550	420	3,430	2,420	280	6,550
13	Commonwealth Ave_Inbound_341	1,210	2,660	1,010	250	5,130	320	4,130	640	50	5,140
14	Quezon Ave_Inbound_341	50	660	240	10	960		290	510	160	960
15	EDSA North_Inbound_341	30	1,030	1,090	460	2,610	10	320	1,330	950	2,610
16	Aurora Blvd West_Inbound_401	600	1,770	920	490	3,780	160	1,870	1,440	350	3,820
17	Aurora Blvd West_Outbound_401	440	1,930	1,220	210	3,800		1,520	2,030	280	3,830
18	EDSA South_Inbound_421	720	3,120	930	540	5,310	210	2,650	1,950	500	5,310
19	EDSA South_Outbound_421	440	4,330	340	200	5,310	120	2,610	2,340	260	5,330
20	EDSA North_Outbound_421		550	270	10	830		250	450	140	840
21	EDSA North_Outbound_441	30	1,190	350		1,570		400	500	670	1,570
	Grand Total	9,650	48,810	24,620	8,150	91,230	1,970	46,590	35,540	7,300	91,400

Table 6. Min/Max/Average IRI by Road Segment

No	Road Section	VIMS Results			Smartphone Results		
		Min of IRI	Max of IRI	Average of IRI	Min of IRI	Max of IRI	Average of IRI
1	Commonwealth Ave Outbound 208	1.51	10.8	4.5	3	12.79	5.32
2	Quirino Highway Outbound 228	1.74	10.21	4.82	2.82	14.45	4.92
3	Muzon-Tungkong Manga Rd East Outbound 228	3.86	9.56	6.22	3.97	8.69	5.94
4	Muzon-Tungkong Manga Rd West Outbound 228	2.19	8.17	4.85	3	7.5	4.8
5	Bocause-SnJoseRd Outbound 228	1.93	8.28	4.18	2.15	9.28	4.14
6	Bocause-SnJoseRd Outbound 248	3.63	6.77	4.91	3.77	6.13	4.74
7	Bocause-SnJoseRd Outbound 249	1.83	11.7	4.94	3.27	11.88	5.23
8	Bocause-SnJoseRd Inbound 301 (DPWH base data)	1.88	13	4.89	2.83	12.42	4.89
9	Muzon-Tungkong Manga Rd West Inbound 301	3.34	9.39	5.3	2.88	7.2	4.9
10	Muzon-Tungkong Manga Rd East Inbound 301	4.1	10.9	6.27	3.94	7.66	5.8
11	Quirino Highway Inbound 321	2.37	9.87	5.09	2.34	11.81	5
12	Commonwealth Ave Inbound 321	1.43	10.35	4.31	2.46	9.06	4.68
13	Commonwealth Ave Inbound 341	1.75	11.34	4.25	2.42	13.74	4.12
14	Quezon Ave Inbound 341	2.66	7.58	4.3	3.25	9.69	5.75
15	EDSA North Inbound 341	2.72	11.21	5.56	2.51	12.65	6.57
16	Aurora Blvd West Inbound 401	1.67	13.16	4.94	2.73	9.32	5.03
17	Aurora Blvd West Outbound 401	2.37	11.56	4.79	3.36	17.54	5.45
18	EDSA South Inbound 421	1.8	16.26	4.61	2.15	10.04	5.03
19	EDSA South Outbound 421	1.89	8.7	4.08	1.93	9.44	5.1
20	EDSA North Outbound 421	3.67	7.62	4.93	3.62	8.5	5.79
21	EDSA North Outbound 441	2.96	6.5	4.31	3.56	10.3	6.66

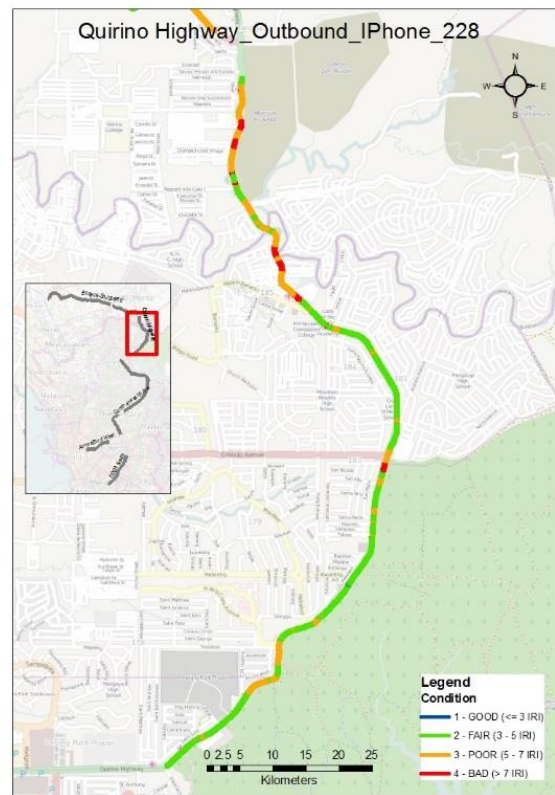
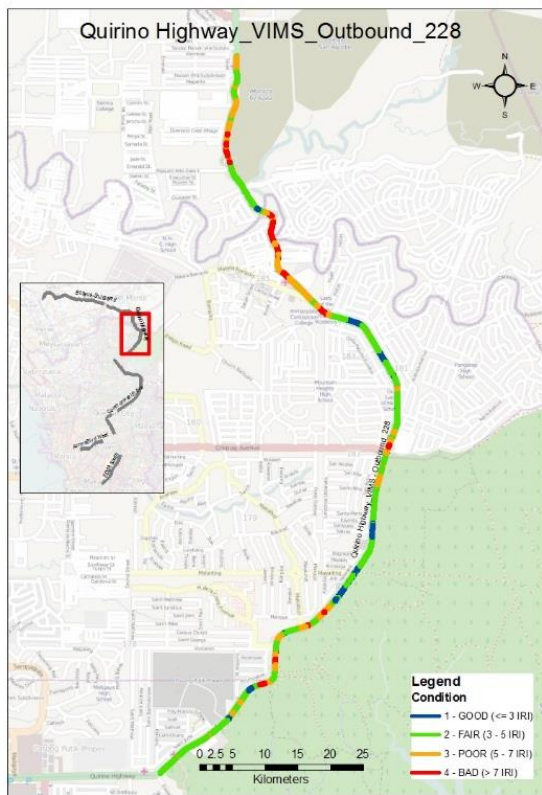


Figure 5. Sample Map of VIMS vs Smartphone IRI (Quirino Highway_Outbound_228)

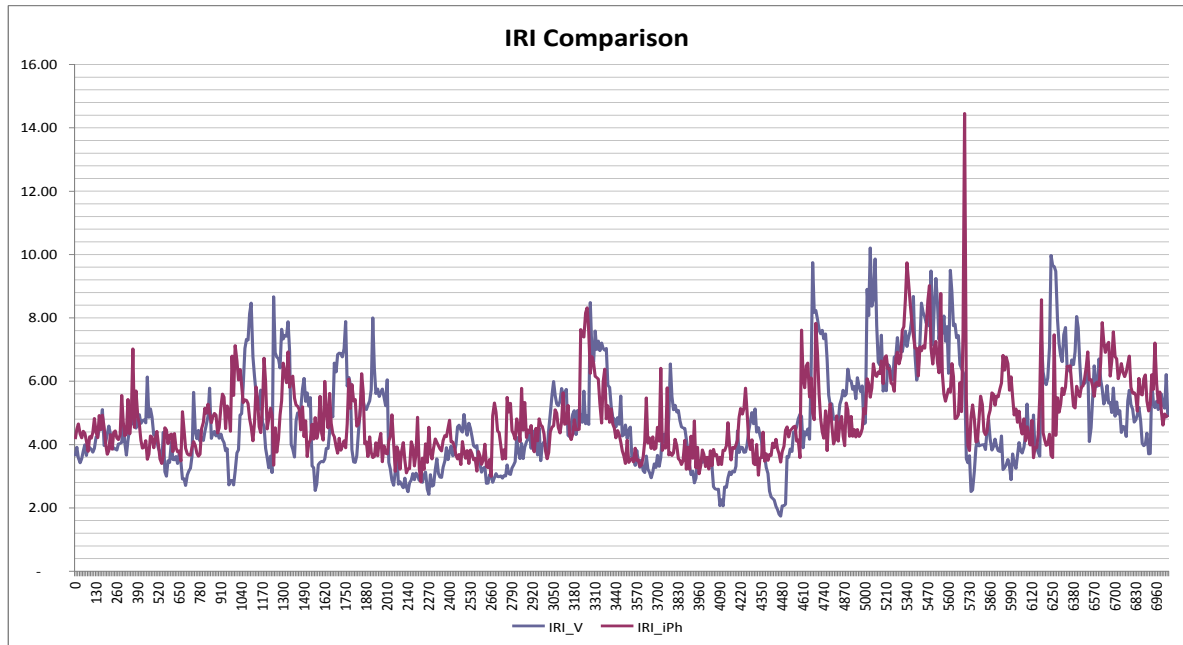


Figure 6. Sample Line Graph of VIMS vs Smartphone IRI (Quirino Highway_Outbound_228)

5. CONCLUSION

The paper developed a cost-effective 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 roughness survey method can be a viable alternative to traditional IRI survey methods.

The study compiled roughness measurement along the case study roads using Vehicle Intelligent Management System (VIMS) and Smartphone Road Roughness Survey Method. It was able to collect usable data on road roughness for the case study roads using both methods. These data were the basis to come up with an IRI equation used by the smartphone road roughness method. Based on the results, 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. The relationship for most initial results of this case study indicates that a linear relationship can be used. The usage of both acceleration (G) and speed parameters from the smartphone survey increases its closeness to VIMS values of IRI. A linear correlation can be observed between VIMS baseline data and smartphone survey data with parameters of acceleration and speed. 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.

The smartphone survey method though has some limitations. 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. The accuracy of the results of the smartphone roughness survey method is highly dependent on GPS and speed readings. Vertical obstructions commonly found in the urban setting such as buildings and elevated railways tend to degrade GPS accuracies.

For future research, it is best to analyze for precision using multiple runs of survey, analyze in both urban and rural areas to see if there are additional relationships that can be ascertained from the type of road being surveyed, and finally a comparative study between Philippine data with other IRI studies in Asia or the world for similar roads.

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