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Pavement Roughness Condition Evaluation: A Literature Review

Mandeep Kaur Arora[1], Mahesh Ram Patel[2], Abhyuday Titiksh[3]
[1, 2]*Department of Civil Engineering, Chhattisgarh Swami Vivekananda Technical University,*
[3]*Department of Civil Engineering, Vishveshvaraya National Institute of Technology Nagpur*

Abstract: This paper consists of a review on the methodologies adopted for determining pavement unevenness so far. Also the various factors contributing to the unevenness of the pavement. Since 19th century researches have been started to monitor pavement profile so that the fatalities and other serious issues caused by irregular pavement profile can be minimized. There are some publications related to parameters of the profile that need to be known before determining its unevenness. Some articles have revealed about the numerical simulation techniques which can be used for correlating roughness parameter with the physical state of profile. Whereas, statistical method uses historic data of the surface. Modern techniques are proved to be the smartest way of getting international roughness indices. Some of the researches are summarized in this paper.
Keywords: Road, roughness, simulation, acceleration, vibration, ride safety

I. INTRODUCTION

Expansion of road network is seen at a considerably high rate since last century. India has built nearly 100,000 km of roads in the last 15 years [1]. As the growth in the pavement section is taking place, the already existing roads are getting deteriorated because of excessive increase in traffic load. Due to uneven atmospheric conditions even high quality pavements are getting deteriorated at a faster rate. Thus, maintenance of the existing road has become a necessity to keep well managed infrastructure.

Many a times, pavement unevenness are responsible for causing fatalities in highway sections. Bad roads also deteriorate the vehicle, driver's performance and even responsible for mental strain. Test results have concluded that the excessive roughness and uneven speed of a vehicle can significantly decrease heartbeat of the driver which impact his response significantly [2]. Thus, a proper classification of roughness parameter is important for controlling ride quality and ensuring safety.

In this paper, some papers were reviewed which had described about the factors responsible for causing pavement roughness as well as methodologies adopted for calculating the unevenness.

II. LITERATURE REVIEW

Many research works have been done in pavement profiling since 19th century. Most of those techniques proved to be reliable in estimating unevenness. Some of the research works related to pavement profiling are summarized below:

A. *Literature Review on Profiling Parameters*

Michael W. Sayers, Thomas D. Gillespie, and Cesar A. V. Queiroz (1986) characterized the road roughness in a universal, consistent, and relevant manner and evaluated standard indices based on the geometric characteristics, road simulation, vehicular characteristics, and spectral analysis of the roughness recorder output. Response type road roughness measurement system based on vehicle simulation was used to calibrate profile. [3]

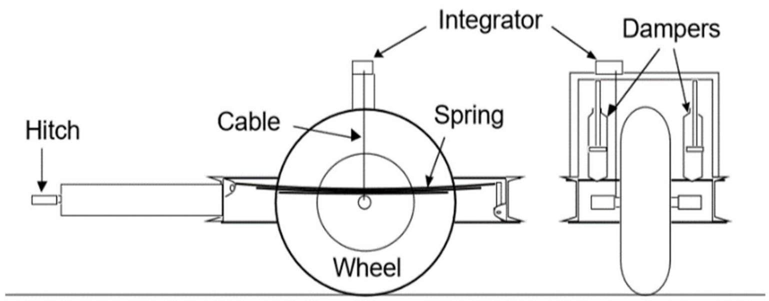


Fig. 1 Response type road roughness measurement system (The BPR Roughometer). Reproduced with permission. Copyright 1986, University of Michigan.

Michael W. Sayers (1998) wrote a little book of profiling for measuring and interpreting road profile. In this book three basic questions were answered i.e. 1) how profilers are used? 2) how it helps? 3) how we can reduce errors? He described three basic parameters of a profiler i.e. a reference elevation, a height relative to the reference, and a longitudinal distance. Where, rod and level were defined as static profiler and Dipstick as a dynamic profiler. He proposed use of Power Spectral Density (PSD) function as a high speed profiling system, which is based on classification of voltage and applied same mathematical function for profile measurement. He also elaborated that longitudinal acceleration and vertical vibration experienced by the rider while moving in a high seat vehicle like truck is higher than that experienced by the rider of a passenger car due to road roughness leading to a situation of discomfort. [4]

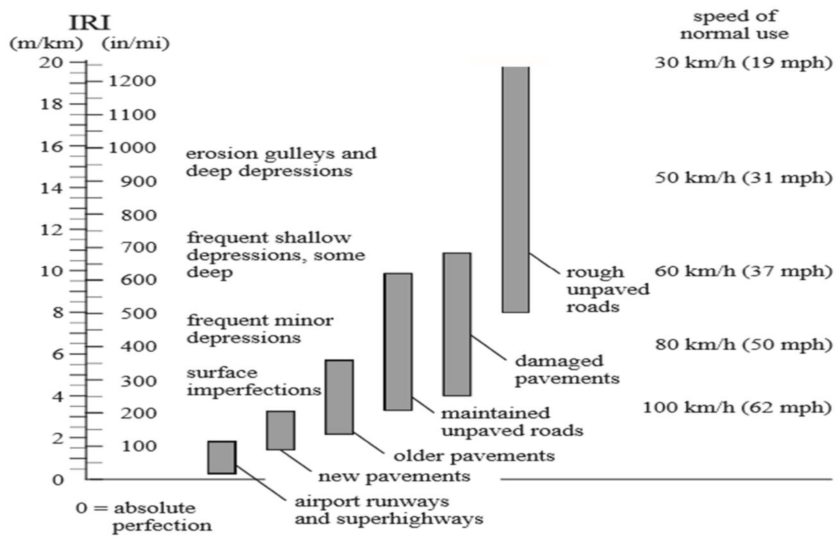


Fig.3 IRI vs different pavement types and speed. Reproduced with permission. Copyright 1998, The Little Book of Profiling.

Peter Mucka and Johan Granlund (2012) dealt with estimating the effect of road profile wavelength contents on the IRI. IRI calculated for a velocity of 20 kmph was found twice as sensitive to velocity of 80 kmph for a local obstacle [5].

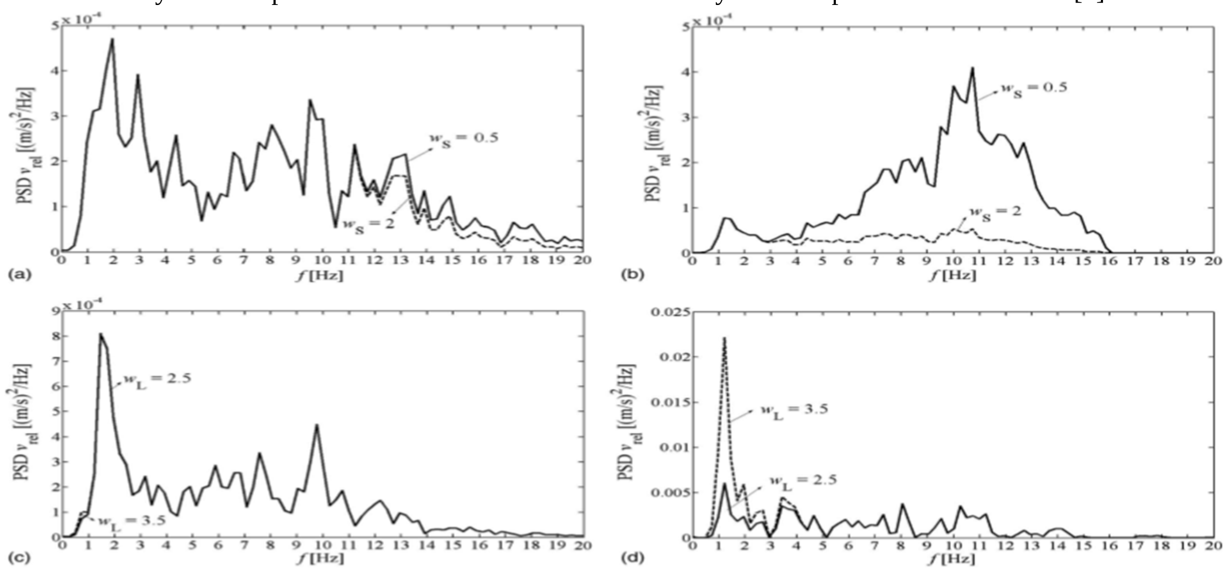


Fig.5 Quarter-car model suspension relative velocity PSD as a function of road profile wavelength contents: short-wave amplitude reduction: (a) 80 kmph (b) 20 kmph; long-wave amplitude increase: (c) 80 kmph (d) 320 kmph. Reproduced with permission. Copyright 2012, ASCE.

Peter Mucka (2016) proposed velocity related IRI limit curves. He quantified ride comfort, ride safety, the dynamic load of the vehicle and road by observing the expected large range of vibration response RMS values for the same level of IRI [5].

B. Literature Review on Different Profiling Technique

M. A. Cundill (1991) devised a simple low- cost pavement roughness data measuring machine i.e. MERLIN (Machine for Evaluating Roughness using Low-cost Instrumentation). This device has been well correlated with the pavement roughness data measuring machine known as Bump Integrator. Also the roughness output obtained is correlated to get the roughness value in terms of IRI (m/km) [6].

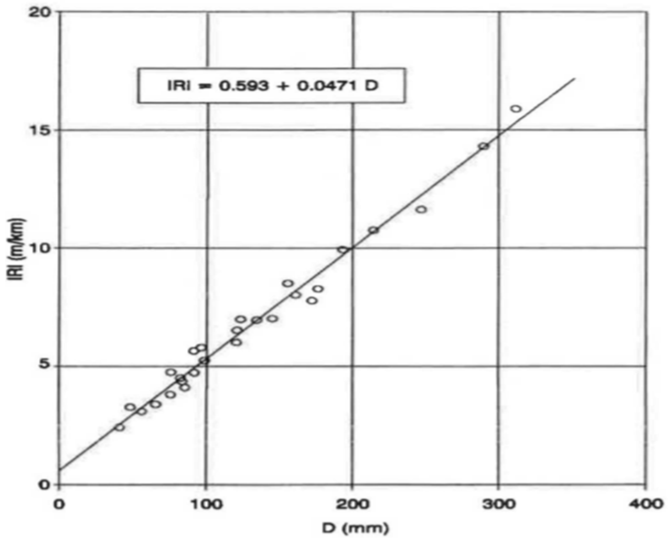


Fig. 7 Relationship between IRI and D. Reproduced with permission. Copyright 1991, Transport and Road Research Laboratory, UK.

Ben Bruscella, Vincent Rouillard, and Michael Sek (1999) analyzed several kilometers of road profile data in frequency as well as amplitude domains. They concluded that spatial acceleration data is a reliable indicator of road roughness [7].

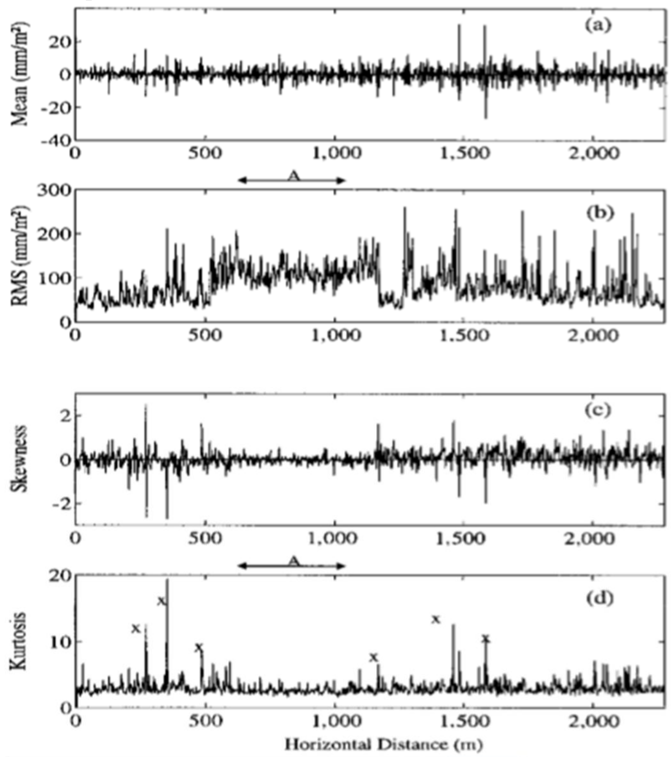


Fig.8 graph for typical road spatial acceleration: (a) moving mean, (b) moving RMS, (c) moving skewness, (d) moving kurtosis. Reproduced with permission. Copyright 1999, ASCE.

Oldrich Kropac and Peter Mucka (2009) proposed a single number indicator defining about the pavement unevenness based on the vehicle vibration response caused by the waviness of the pavement profile. They also proposed modified IRI values which are affected by speed, and assessment of subjective rating methods [8].

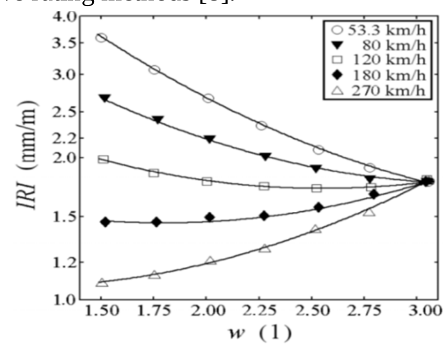


Fig.9 Dependence of IRI on waviness (w). Reproduced with permission. Copyright 2009, ASCE.

Manish Paul and Rumi Sutradhar (2014) derived a generalized equation to get the values of IRI using Bump Integrator from different speeds to a standard speed of 32kmph by using SPSS software [9].

$$(BI)_{32} = 0.956(BI)_V + 0.842V - 25.544 \; (R^2 = 0.958)$$

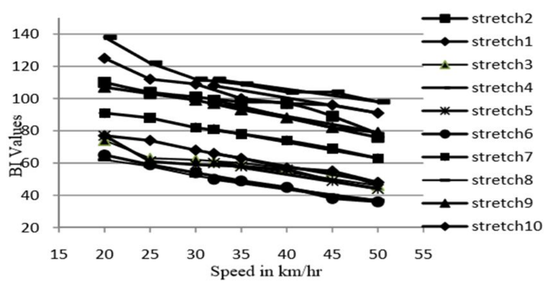


Fig.10 BI values on different stretches at different speeds. Reproduced with permission. Copyright 2014, IJCE.

Marwan Hafez, Khaled Ksaibati, and Richard Anderson- Sprecher (2016) developed uni- variable regression multiple imputation models by using historical PMS data and statistical technique. And it was concluded that by use of historical data, a good estimation of pavement data can be obtained [10].

Year	ADT < 200 vehicles per day	ADT ≥ 200 vehicles per day		
	Pattern	Pattern (1)	Pattern (2)	Pattern (3)
1997			√	√
1998	√	√		
1999			√	√
2000	√	√		
2001			√	√
2002	√	√		
2003			√	√
2004	√	√		
2005			√	√
2006			√	
2007	√	√		√
2008			√	
2009	√	√		√
2010			√	
2011	√	√		√
2012			√	
2013	√	√		√

Fig.11 History of data collection patterns of the case study. Reproduced with permission. Copyright 2016, ASCE.

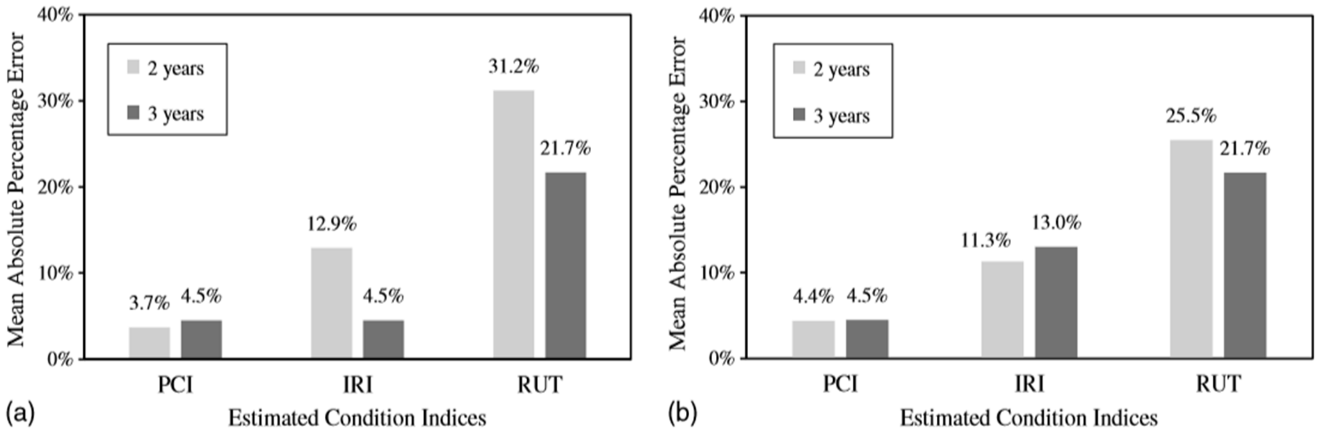


Fig.12 Assessment of imputation analysis for case study: (a) when ADT < 200 vehicles per day; (b) when ADT≥200 vehicles per day. Reproduced with permission. Copyright 2016, ASCE

Khaled Ksaibati, Ronald Mcnamara, William Miley, and Jamshid Armaghani (2016) performed a nationwide survey to identify the trends of various departments of transportation regarding roughness data collection and analysis. They concluded that most of the states are using laser-type road profilers for measuring roughness and worldwide used roughness indices is IRI.

Zhiming Zhang, Chao Sun, Raj Bridgelall, and Mingxuan Sun (2018) applied machine learning method by connecting two vehicles and the acceleration responses achieved gave the value of road roughness in terms of IRI. They prepared a speed normalization model by using quarter car model.

C. Literature review on Smartphone based Profiling Technology

Kasun De Zoysa, Kasun Chamath, Keppitiyagama chamath (2007) designed a road surface monitoring system based on a sensor network Bus Net. Bus Net is an ideal approach in building vehicle based data network because public transport uses the road that we want to monitor and the most economical attempt for monitoring road condition [11].

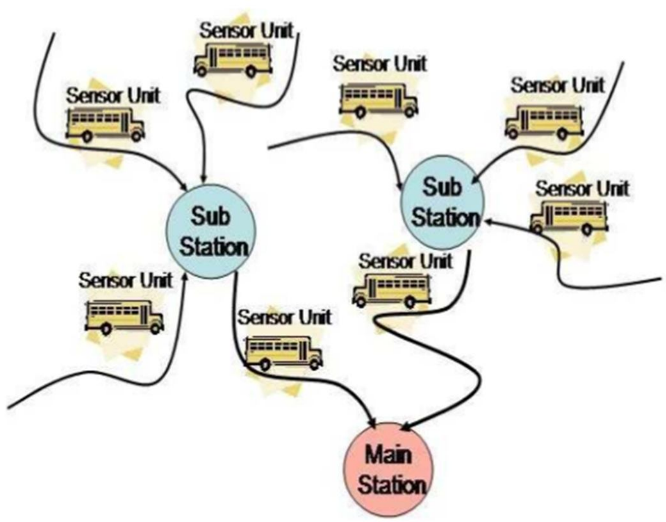


Fig.14 Bus Net. Reproduced with permission. Copyright 2007, ACM.

G. Alessandroni, L. C. Klopfenstein, S. Delpriori, and M. Dromedari (2014) designed a three- tiered architecture i.e. a mobile application at user level, a back end server using a geographic information system, and a graphical front end based on cloud platform for visualization. They had collected raw data by inexpensive devices on personal vehicles, thus transformed into a clear overview of road quality which can be used for the benefit of institutions or drivers [12].

Shahidul Islam, William G. Buttlar, Roberto G. Aldunate, and William R. Vavrik (2014) collected IRI values at two test sites using smartphone technology and validated those values with the help of values of standard Inertial Profiler. They found that in 37 out of 40 tests, values were within 15% of the standard results. A simple linear calibration is able to bring the result in close correlation and can be accomplished in practice, if required [13].

Trevor Hanson, Coady Cameron, and Eric Hildebrand (2014) calculated IRI values from different smartphones to identify variances in IRI due to smartphone device type, mounting arrangement, vehicle speed and type and compared with class1 profiler. They concluded that significant factor causing variation in IRI values are device type, mounting arrangement and vehicle type [14].

Table 3. Average calculated IRI for all tests.

Test	Vehicle	Device	Mount	Speed (km/h)	Avg. IRI (m/km)	Std. dev.	CV	% diff. from profiler
B1	Profiler	Profiler	Profiler	80	2.6	0.029	1.12	0.0
B2	Profiler	iPhone 5	Windshield	80	2.73	0.2	7.33	5.0
A	Compact	iPhone 5	Windshield	80	2.74	0.16	5.84	5.4
B	SUV	iPhone 5	Windshield	80	2.29	0.079	3.45	−11.9
C	Truck	iPhone 5	Windshield	80	2.48	0.2	8.06	−4.6
D	Compact	Galaxy SIII	Windshield	80	2.58	0.075	2.91	−0.8
E	Compact	Z10	Windshield	80	2.65	0.058	2.19	1.9
F	Compact	iPhone 5	T-bracket	80	2.35	0.11	4.68	−9.6
G	Compact	iPhone 5	Vent	80	4.83	0.44	9.11	85.8
H	Compact	iPhone 5	Windshield	50	2.41	0.072	2.99	−7.3
I	SUV	iPhone 5	Windshield	50	2.63	0.054	2.05	1.2
J	Truck	iPhone 5	Windshield	50	2.34	0.14	5.98	−10.0

Table 4. Effect of varying smartphone devices on calculated IRI.

Test	Vehicle	Device	Mount	Speed (km/h)	Avg. IRI (m/km)	Std. dev.	CV	% diff. from profiler
D	Compact	Galaxy SIII	Windshield	80	2.58	0.075	2.91	−0.8
E	Compact	Z10	Windshield	80	2.65	0.058	2.19	1.9
A	Compact	iPhone 5	Windshield	80	2.74	0.16	5.84	5.4

Table 5. Effect of varying mounting devices on calculated IRI.

Test	Vehicle	Device	Mount	Speed (km/h)	Avg. IRI (m/km)	Std. dev.	CV	% diff. from profiler
A	Compact	iPhone 5	Windshield	80	2.74	0.16	5.84	5.4
F	Compact	iPhone 5	T-bracket	80	2.35	0.11	4.68	−9.6
G	Compact	iPhone 5	Vent	80	4.83	0.44	9.11	85.8

Table 6. Effect of varying vehicle types and speeds on calculated IRI.

Test	Vehicle	Device	Mount	Speed (km/h)	Avg. IRI (m/km)	Std. dev.	CV	% diff. from profiler
A	Compact	iPhone 5	Windshield	80	2.74	0.16	5.84	5.4
H	Compact	iPhone 5	Windshield	50	2.41	0.072	2.99	−7.3
B	SUV	iPhone 5	Windshield	80	2.29	0.079	3.45	−11.9
I	SUV	iPhone 5	Windshield	50	2.63	0.054	2.05	1.2
C	Truck	iPhone 5	Windshield	80	2.48	0.2	8.06	−4.6
J	Truck	iPhone 5	Windshield	50	2.34	0.14	5.98	−10.0

Shahidul Islam, William G. Buttlar, Roberto G. Aldunate, and William R. Vavrik (2014) again measured pavement roughness using cellphone based technology and concluded that IRI values measured at lower speed deviated from a unity line. Also concluded that measurement of pavement roughness is improved when vehicle vertical acceleration data was collected at higher rate [15].

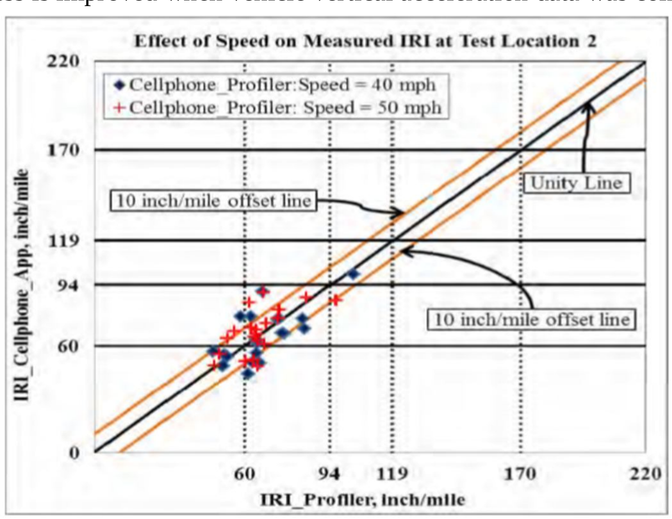


Fig.16 Effect of speed on IRI measurement at test location. Reproduced with permission. Copyright 2014, ASCE.

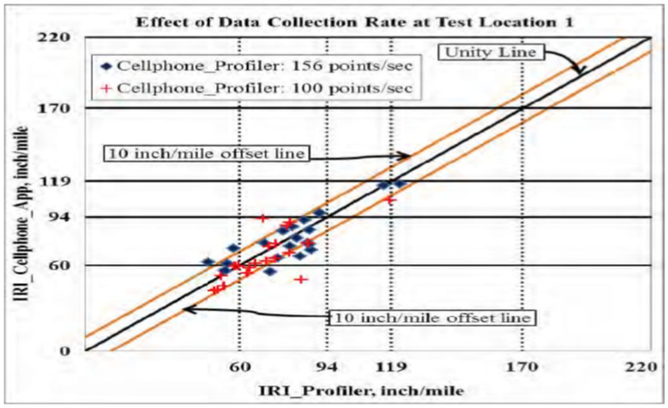


Fig.17 Effect of data collection rate on IRI measurement at test location. Reproduced with permission. Copyright 2014, ASCE.

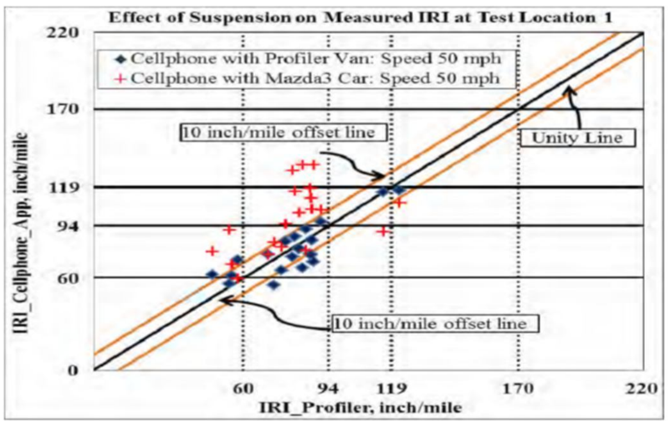


Fig.18 Effect of vehicle suspension on IRI measurement at test location. Reproduced with permission. Copyright 2014, ASCE.

Rajiv Kumar, Abhijit Mukherjee, and V.P. Singh (2016) performed crowd sourcing i.e. distributed smartphones to the people for gathering road roughness parameter. Used a fuzzy system to classify the roughness parameter. Presented road surface condition on google map by different colors corresponding to surface classes. And the roads were monitored visually for justification of the Smartphone technology [16].

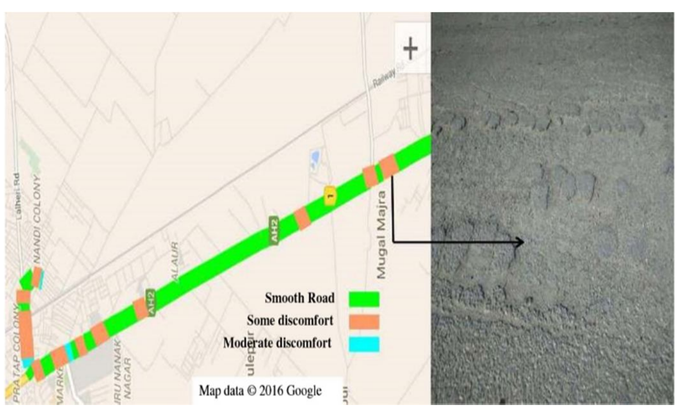


Fig.19 Road segment with some patches of discomfort (map data © Google 2016; image by Rajiv Kumar). Reproduced with permission. Copyright 2016, ASCE.

Waleed Aleadelat, Khaled Ksaibati, Cameron H. G. Wright and Promothes Saha (2018) covered different roadway segments with various geometric features using smartphones for measuring IRI and compared with referenced IRI values of standard profiler by using MATLAB, signal processing and pattern recognition technique. They concluded that type of smartphone is an important factor in measuring profile. Whereas, shape and frequency obtained in the tests were highly similar.

III. RESULTS AND DISCUSSION

Reviewing of various literature has revealed certain important results which need to be discussed here. These are the parameters obtained:

1) *Factors Responsible for causing Roughness:* there can be various factors responsible for causing pavement roughness. Some are vehicular characteristics, road geometry characteristics, road simulation, and waviness of the pavement profile.
2) *Factors Affecting Magnitude of Jerk:* vehicles having high seat like truck gives higher jerk as compared to a passenger car.
3) *Factors Indicating Road Roughness:* vehicle simulation responses due to vertical vibration, spatial acceleration data, and also historical PMS data gives the value of roughness by means of certain measurements.
4) *Models Prepared to Describe Roughness:* a speed normalization model based on quarter car formula was developed by Zhiming Zhang (2018) to describe road roughness by the response of acceleration data obtained.
5) *Factors affecting Efficiency of Roughness Output:* factors responsible for varied pavement profile output are the speed of the vehicle, mounting arrangement of the sensor, vertical vibration response of the vehicle, vehicle type, device type used as a sensor, etc.
6) *Techniques for Measuring Unevenness:* there are various techniques adopted for measuring unevenness. Some are as follows:

a) Statistical data collection and surface condition evaluation technique
b) Laser profiler technique
c) Low- cost MERLIN technique
d) Machine learning technique by connecting two or more vehicles
e) Sensor based methods like Bus Net, smartphone applications based on GPS, accelerometer, gyroscope embedded in it.

IV. CONCLUSION

This paper was based on the review of different papers to get an idea of the pavement roughness measurement data, techniques of measuring data, as well as factors responsible for causing roughness. This study, made a conclusion that the roughness of the pavement is the result of waviness of the road, past experienced stresses in the pavement, type of the vehicle following the road, loading at the pavement, etc. Collection of pavement roughness data can be done by various means like collecting statistical data, vertical vibration response, amount of jerk experienced, etc. The smartest technique of collecting pavement roughness data is the use of smartphone application. Still, more researches are going on with this technique to get the best possible set of the device type, speed and mounting arrangement in order to get the most accurate result of pavement roughness.

V. ACKNOWLEDGMENT

This paper deals with study of techniques used for measuring pavement unevenness. The author would like to thank Vikas Kumar Reddy, Ashish Rathore and Gaurav Pandey for their assistance in collecting data. Finally, the author also thanks the viewers for their valuable comments on this paper.

REFERENCES

[1] Annual Report of Highway 2015

[2] Zhang, Jinxi, Yanhua Du, and Ruiwei Su. "Investigating the relationship between pavement roughness and heart-rate variability by road driving test." Proceedings of the 3rd International Conference on Road Safety and Simulation, Washington, DC, USA. 2011.

[3] Sayers, Michael W. "The international road roughness experiment: Establishing correlation and a calibration standard for measurements." (1986).

[4] Sayers, Michael W. "The little book of profiling: Basic information about measuring and interpreting road profiles." (1998).

[5] Múčka, Peter. "Road roughness limit values based on measured vehicle vibration." Journal of Infrastructure Systems23.2 (2016): 04016029.

[6] Cundill, M. A. "MERLIN-A Low-Cost Machine for Measuring Road Roughness in Developing Countries." Transportation Research Record 1291 (1991): 106-112.

[7] Bruscella, Ben, Vincent Rouillard, and Michael Sek. "Analysis of road surface profiles." Journal of Transportation Engineering 125.1 (1999): 55-59.

[8] Kropáč, Oldřich, and Peter Múčka. "Alternative single-number indicator of longitudinal road unevenness." Canadian Journal of Civil Engineering 36.3 (2009): 389-401.

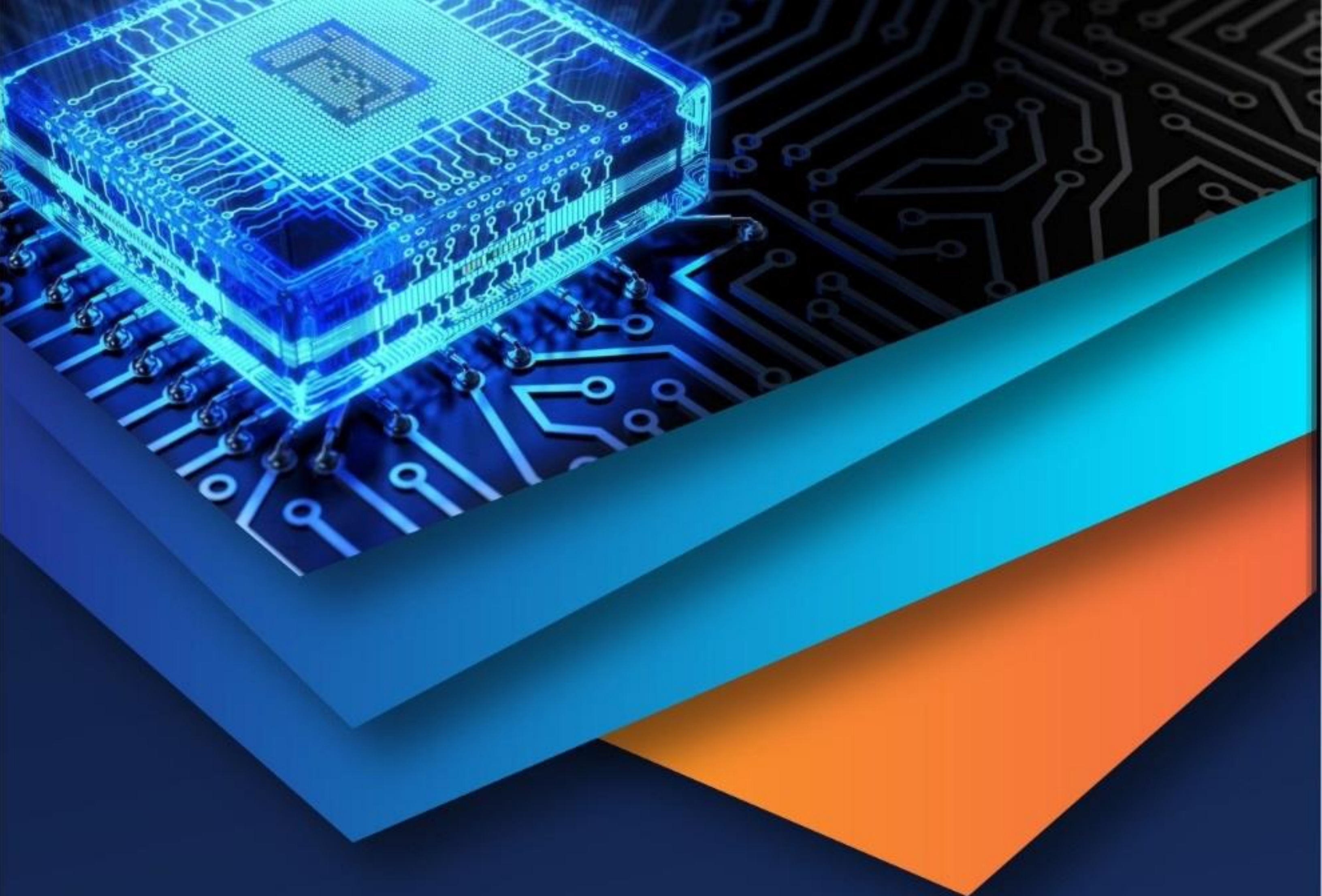
[9] Pal, Manish, and Rumi Sutradhar. "Pavement Roughness Prediction Systems: A Bump Integrator Approach." World Academy of Science, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering 8.12 (2014): 1258-1261.

[10] Ksaibati, Khaled, et al. "Pavement roughness data collection and utilization." Transportation Research Record: Journal of the Transportation Research Board 1655 (1999): 86-92.

[11] De Zoysa, Kasun, Chamath Keppitiyagama, Gihan P. Seneviratne, and W. W. A. T. Shihan. "A public transport system based sensor network for road surface condition monitoring." In Proceedings of the 2007 workshop on Networked systems for developing regions, p. 9. ACM, 2007.

[12] Alessandroni, G., et al. "Smartroadsense: Collaborative road surface condition monitoring." Proc. of UBICOMM-2014. IARIA (2014): 210-215.

[13] Islam, Shahidul, et al. "Measurement of pavement roughness using android-based smartphone application." Transportation Research Record 2457.1 (2014): 30-38.
[14] Hanson, Trevor, Coady Cameron, and Eric Hildebrand. "Evaluation of low-cost consumer-level mobile phone technology for measuring international roughness index (IRI) values." Canadian Journal of Civil Engineering 41.9 (2014): 819-827.
[15] Islam, Shahidul, William G. Buttlar, Roberto G. Aldunate, and William R. Vavrik. "Use of cellphone application to measure pavement roughness." In T&DI Congress 2014: Planes, Trains, and Automobiles, pp. 553-563. 2014.
[16] Kumar, Rajiv, Abhijit Mukherjee, and V. P. Singh. "Community sensor network for monitoring road roughness using smartphones." Journal of Computing in Civil Engineering 31.3 (2016): 04016059.
[17] Hafez, Marwan, Khaled Ksaibati, and Richard Anderson-Sprecher. "Utilizing statistical techniques in estimating uncollected pavement-condition data." Journal of Transportation Engineering 142.12 (2016): 04016065.



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