Eduvest – Journal of Universal Studies
Volume 4 Number 11, November, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

CALIBRATION OF PROTOTYPE "ULTRASONIC SURFACE ROUGHMETER" WITH GAP MAN PROFILOMETER

Eko Wahyu Utomo[1], Pratikso[2], Siegfried[3]
[1,3]Universitas Langlangbuana, Bandung, Indonesia
[2]Universitas Islam Sultan Agung Semarang, Indonesia
Email: utomoeko042@gmail .com

ABSTRACT

In road network evaluations, road performance is assessed from structural and functional aspects. Typically, road surface roughness measurements rely on expensive, imported instruments. Therefore, this research developed a prototype roughness measuring tool using an ultrasonic sensor, which is more cost-effective. This study aims to calibrate the "Ultrasonic Surface Roughmeter" prototype and evaluate its accuracy in measuring the International Roughness Index (IRI) as a reference for road maintenance. The prototype was tested through calibration with the standard tool, Gap Man Working Profilometer. Data were collected from several road segments of a specified length, and measurement results were analyzed through descriptive statistics to compare data from both tools. The calibration results indicate that the prototype achieved a high accuracy level, with a correlation value of 99.51% and a confidence level of 97.05%. The Cronbach's alpha value of 1.0 shows excellent internal consistency, with an average measurement difference of approximately 3.11%.The "Ultrasonic Surface Roughmeter" prototype can serve as a valid and economical alternative for measuring road surface roughness.

KEYWORDS *roughmeter, ultrasonic, highway, roadworthiness*

INTRODUCTION

Roads in Indonesia are a cohesive network system to connect all parts of Indonesia as infrastructure. (Government of the Republic of Indonesia 2004). Due to the very important benefits of road maintenance and construction, it will be a priority in the development of planning and implementation as well as maintenance. (Yoga Triardhana, Bandi Sasmito, and Firman Hadi 2021).. However, there must be a way to maintain smooth travel because as the road ages, it will deteriorate (Alhasan 2015; Alhasan et al. n.d.; Bulaha 2018).

How to cite:	Eko Wahyu Utomo, et.al. (2024). Calibration Of Prototype "Ultrasonic Surface Roughmeter" With Gap Man Profilometer. *Journal Eduvest*. *4*(11), 9869-9880
E-ISSN:	2775-3727
Published by:	http://eduvest.greenvest.co.id

Based on the role and position of road maintenance today and in the future, as well as looking at the experience of road maintenance implementation in the past, it is necessary to take concrete steps to strengthen road maintenance management today and in the future. (Directorate General of Highways 2011) Road maintenance in the past has been inadequate due to the weakness of several factors, including handling methods, limited trained personnel, limited equipment units, and so on. (Prijo Sadewo 1995; Richard W. V. Uguy and Vanda S. Rompis 2021).

Therefore, effective road management is essential. The impact of traffic intensity and excessive load will affect the quality, so maintenance measures need to be taken to keep the road in a stable and well-maintained condition. To carry out road treatments accurately, it is important to carry out preliminary planning according to data from careful condition surveys.(Indonesian Public Works 1995; Suwardo and Heru Budi Utomo 2020)

Based on the role and position of road maintenance in the present and future, and looking at the past experience of road accounting, we need to take concrete steps in monitoring the management of road maintenance in the present and future. Road maintenance in the past has been inadequate due to the weakness of several factors, such as handling methods, restrictions on trained personnel, limited equipment units, and so on.(Wahyu, Pratikso, and Siegfried 2023)..

To evaluate the condition of the pavement, one method is to use a roughness measuring device called a rough meter, which aims to measure the consistency and obtain the straightness value of the longitudinal surface of the road in IRI values.(ASTM International, 2003; Bahaaeldin Hassan, 2021)

This research was conducted to determine the unevenness value of the road with different tools and research studies and different tools, namely using a rough meter with an ultrasonic type sensor, which is named ultrasonic surface rough meter. With this research, can be considered for experts in conducting road maintenance planning on-site and also trying to make an IRI-Based Road Function Performance Evaluation with "Ultrasonic Surface Rough meter", and this research focuses more on calibrating the "Ultrasonic Surface Rough meter" Prototype tool with a standard tool, namely the Gapman Working Profilometer.

This study presents an innovation in the method of measuring road surface roughness using ultrasonic sensors that are more economical than conventional imported tools. The "Ultrasonic Surface Roughmeter" prototype was developed as a more affordable alternative solution with a high level of accuracy that is close to standard tools. This offers a new contribution to road measurement technology, especially for countries with limited budgets for road infrastructure maintenance.

This study aims to develop and calibrate the "Ultrasonic Surface Roughmeter" prototype with the standard Gap Man Working Profilometer tool. Thus, this prototype is expected to provide accurate measurement results against the International Roughness Index (IRI) as a reference for more efficient highway planning and maintenance.

This study provides several benefits:

1. Facilitating the evaluation of road conditions with more economical and effective tools so that they can be widely implemented in various road maintenance projects.

2. Increase the efficiency of road maintenance budgets with tools that have lower production costs but still have high accuracy.
3. Provide accurate data on road surface roughness, which can support strategic planning in extending the service life of highways and increasing the comfort of road users.

RESEARCH METHOD

Road condition is an index that objectively uses certain criteria or ranges to determine the level of deterioration of a road, and there are many types of road condition measurements. (Transportation Association of Canada, 2006)

From these various indices, there is a difference between the functional and structural conditions of the pavement. The difference can be used in the same index when looking at the Remaining Life. The remaining service life is estimated based on the total number of vehicles passing that year, with the surface still in functional and structural condition, with only routine maintenance. (Baladi & GY, 1991)

In this study, the IRI value can be used to see the function of the road, while the Pavement Modulus is used to see the pavement structure. The IRI value is obtained from the results of a road surface roughness survey using a roughness meter.(Dewi Asri Anugrah, 2021)

Pavement damage (volume and severity) is obtained from the Road Survey (SRD), which aims to build and develop the road network, while the road surface roughness value in the longitudinal direction is obtained using the IRI value expressed in m/km. (SNI 03-3426-1994, 1994)

The pavement condition value obtained from the Surface Distress Index (SDI) is a system value from visual observations that can be used as a reference for maintenance. From this visual observation, it can be used to identify based on the level of road damage (Golov et al., 2022).

Meanwhile, to determine the condition of road damage, an IRI value of <4 means good to light damage, an IRI value of 4 - 8 means light damage, an IRI value of 8 - 12 means light to heavy damage, and an IRI value of 12 - 16 means heavy damage (Directorate General of Highways 2011).

The prototype ultrasonic surface roughmeter is a road surface unevenness measuring instrument that is less expensive but also more accurate than existing roughmeter equipment to evaluate the performance of road functions based on its surface. While the Gap Man Working Profilometer is a measuring instrument road surface unevenness that operation is pushed across the measured surface by one operator, this tool is lightweight and has a choice of settings and controls that can be selected and has an IRI measurement mode and can display calculations and real-time display of surface profile parameters and is equipped with an integrated GPS unit determines and stores the location of measurements and can be connected to a USB or Bluetooth computer, which is used as a calibrator.

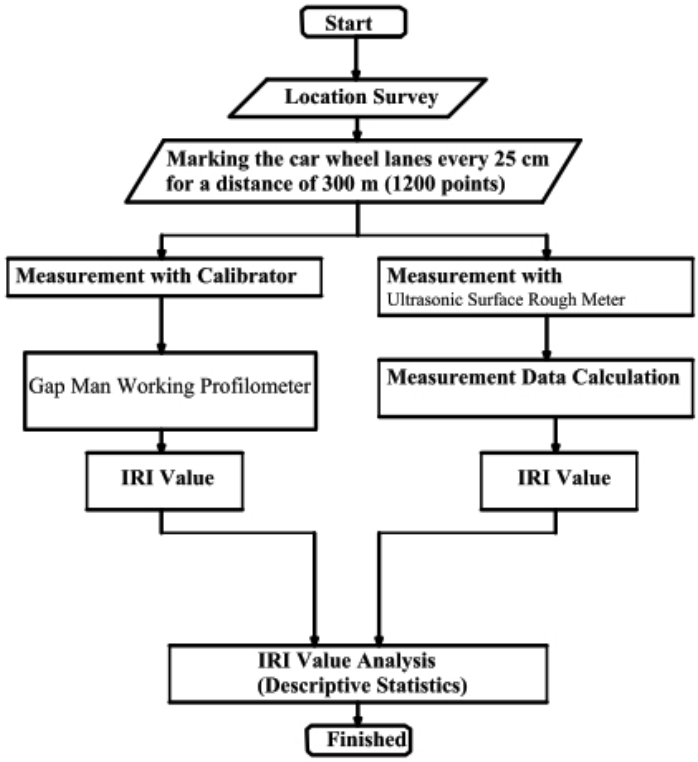

Figure 1. Calibration flow chart

The rare step is to start with a survey and proceed with marking the vehicle wheel track lane every 25 cm along 300 m at each measurement location point. Furthermore, measurements were taken with standard measuring instruments and also with the Prototype *"Ultrasonic Surface Roughmeter"* with the *Gap Man Working Profilometer* measuring instrument, and the results of these measurements were calculated and Descriptive Statistical Analysis.

MEASUREMENT LOCATION

The calibration locations that have been determined are as follows

1. Jalan Prof. KH Anwar Musaddad on the left, Tj. Kamuning, Tarogong Kaler Sub-district, Garut Regency, West Java 44151, starting from coordinates 7°10'37.5 "S 107°54'19.2 "E and ending at coordinates 7°10'28.6 "S 107°54'15.1 "E (SP 3), with a distance of 300m.
2. Prof. KH Anwar Musaddad Street on the right, Tj. Kamuning, Tarogong Kaler Sub-district, Garut Regency, West Java 44151, starting from coordinates 7°10'30.1 "S 107°54'16.2 "E and ending at coordinates 7°10'38.9 "S 107°54'20.4 "E (SP 4), with a distance of 300m.

Figure 2. Calibration Location

Figure 3. Photo of calibration location

Data Analysis

The measurement results were analyzed using descriptive statistics to compare the results of the prototype with the standard tool. Comparisons were made through the calculation of mean values, correlations, and Cronbach's alpha to measure the internal consistency and accuracy level of the prototype. In addition, the percentage difference between the measurement results of the two tools was calculated to determine the level of error or difference in accuracy.

Supporting Instruments

In addition to the main measurement tool, this study used a GPS device to determine the exact measurement location and to link the measurement results to a specific location. The data obtained were stored in a format compatible with statistical analysis software.

Calibration Procedure

The calibration process begins with marking the path to be measured every 25 cm for 300 meters. After the marking was completed, measurements were taken using the "Ultrasonic Surface Roughmeter" prototype and the Gap Man Working Profilometer. Data from both tools were then analyzed to determine the level of accuracy and consistency.

RESULT AND DISCUSSION

International Roughness Index) as follows: To determine the IRI value, four parameters are calculated from the measured road surface profile and are the dynamic responses of vehicles passing over the measured road profile surface. The solution of these four parameters from all elevations except the first point. (Bahaaeldin Hassan, 2021; M. W. Sayers et al., 1986a).To initialize the parameters, the average slope used in the first 11 m or 0.5 s was used at a vehicle speed of 80 m/km, and the values were set (M. W. Sayers, Gillespie, and Paterson, 1986) After solving the above equations, solve the four recursive equations starting from point 2 to point n (number To be faster according to (M. M. Sayers, 1995) the IRI value can be calculated by the following equation:

$$IRI = \frac{1}{(n-1)} \sum_{i=2}^{n} RSi$$

1

(M. W. Sayers, Gillespie and Paterson, 1986) (M. W. Sayers et al., 1986b)

$$\frac{dz(t)}{dt} = \underline{A} * z(t) + B * y(t)$$ (M. M. Sayers, 1995)

2

where:

z = is a vector of 4 variables Z from Equations 1 - 7

A = 4 x 4 description of model dynamics

B = 4 x 1 vehicle description with profile interaction

y(t) = input for the profile on the moving vehicle.

$$A = \begin{bmatrix} two0 & 1 & 0 & 0 \\ -K2 & -C & K2 & C \\ 0 & 0 & 0 & 1 \\ K2/u & C/u & -(K1+K2)/u & -C/u \end{bmatrix} B = \begin{bmatrix} one0 \\ 0 \\ 0 \\ K1/u \end{bmatrix}.$$

3

The coefficient S can be calculated using the values of the four constants. (M. M. Sayers, 1995)

$$ST = e^{A*dt}$$

4

The image below can show and check the valid IRI calculation, which also functions as input.

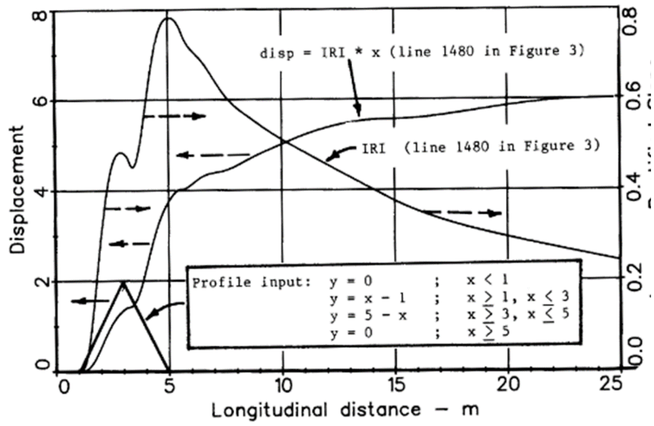

Figure 4. Custom profile input used to check the IRI calculation program Source: M. W. Sayers, Gillespie and Paterson, 1986

Calculation of IRI values with a quarter-car simulation model. The model parts are the spring-mass part, and the non-spring mass part, as shown in Figure 2 (S. L. Chen et al., 2020) made the following equation (M. M. Sayers, 1995; M. W. Sayers et al., 1986a)

$m_s Z''_s + c_s (Z'_s - Z'_u) + k_s (Z_s - Z_u) = 0$, 5

$m_s Z''_s + m_u Z''_u + k_t (Z_u - y) = 0$ 6

dividing the two segments of Equations (5) and (6) by ms simultaneously, the equations of motion can be simplified to Equations (7) and (8) (Chen et al., 2020)

$Z''_s + (Z'_s - Z'_u) + K_2 (Z_s - Z_u) = 0$, 7

$Z''_s + u\ddot{Z}_u + K_1 Z_u = K_1 y$ 8

where

C = c_s / m_s $=6(1/s)$

u = m_u / m_s $=0.15$

$K =_1$ k_t / m_s $=65.3\ (1/s)^2$

$K =_2$ k_s / m_s $=63.3\ (1/s)^2$

Equation (9) to calculate the IRI value

$\text{IRI} = \frac{1}{L} \int_0^L \left| Zs - Zu \right| dx$, 9

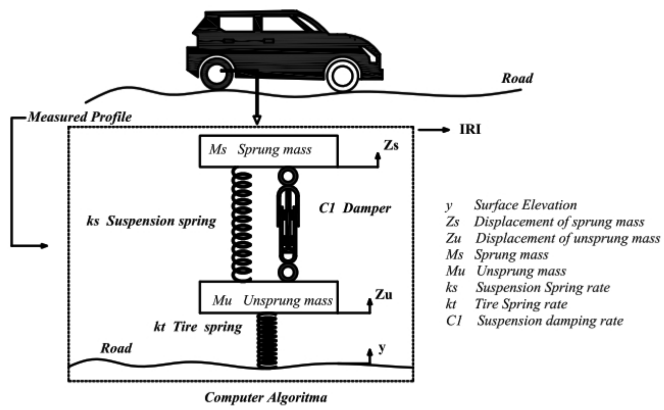

Figure 5. Illustration of IRI value calculation Source: Chen et al., 2020

Calibration Result

The calculated data is compared with the existing reference data from the measurement of the calibrator using the Gap Man Working Profilometer. The table below presents data from the measurement results with the Ultrasonic Surface Roughmeter and data from the Gap Man gap-working profilometer measurement.

Table 1. Calculated IRI Value Data measured by Ultrasonic Survace Roughmeter and Reference Data measured by Gap Man Working Profilometer

No.	SEGMENT	IRI USR	IRI REFERENCES	Difference between USR and REFERENCE IRI Data	
				difference (Δ)	%
1	SP 3, 0-100 m	6.04	5.80	0.24	4.14%
2	SP 3, 100-200 m	6.84	6.70	0.14	2.09%
3	SP 3, 200-300 m	7.33	7.50	0.17	2.27%
4	SP 4, 0-100 m	5.01	4.80	0.21	4.38%
5	SP 4, 100-200 m	5.75	5.70	0.05	0.88%
6	SP 4, 200-300 m	4.93	4.70	0.23	4.89%
Total		**35.900**	**35.200**	**1.040**	**18.64%**
Average		**5.983**	**5.867**	**0.173**	**3.11%**

Table 1 shows a comparison of the results with the Ultrasonic Surface Roughmeter and data from the Gap Man Working Profilometer measurements. The table illustrates the difference between the USR measurement results and the reference data from the Gap Man Working Profilometer and IRI meter measurements, which are relatively very small at less than 5%, the average value is only 3.11%.

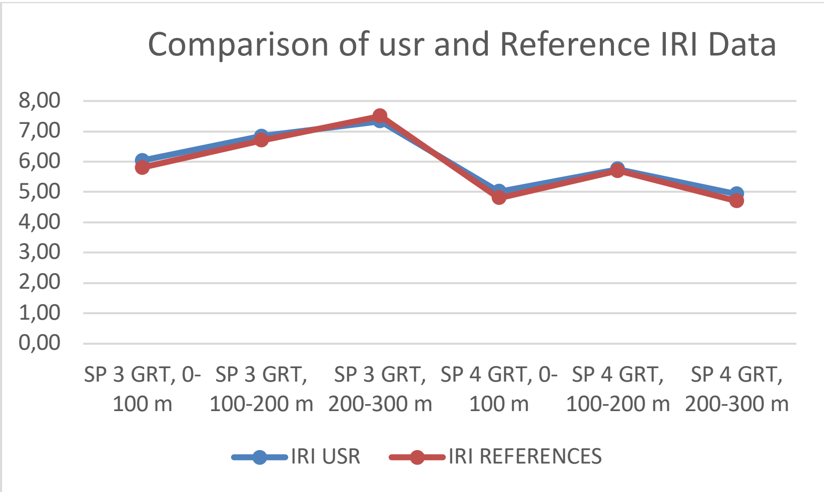

Figure 6. Comparison Chart of Calculated IRI Value Data measured by Ultrasonic Survace Roughmeter and Reference Data measured by Gap Man Working Profilometer

Table 1. Descriptive Statistics Results of Calculated IRI Value Data measured by Ultrasonic Survace Roughmeter and Reference Data measured by Gap Man Working Profilometer

No.	Descriptive Statistics	IRI USR	IRI REFERENCES	difference (Δ)
1	Average (Mean)	5.86667	5.98333	0.116667
2	Median	5.75000	5.89500	0.145000
3	Frequent value (Mode)			
4	Standard Deviation	13.28908	13.60315	0.314072
5	Variance or Sample Variance	1.17867	0.93239	0.24628
6	Difference Range	2.80000	2.40000	0.400000
7	Minimum	4.70000	4.93000	0.230000
8	Maximum	7.50000	7.33000	0.170000
9	Confidence Level	97.05%	97.10%	0.05%
10	Correlation			99.51%
11	Cronbach's alpha			1.00000
12	Relative Standard Error (RSE)			1.95%

Table 2 shows the results of the calculation of Descriptive Statistics of USR measurement data compared to the calibrator measurement data (Gap Man Working Profilometer). The Confidence Level value (a level of confidence that measures the extent to which statistics can estimate parameters correctly.) is 97.05% for USR data, and Reference Data is 97.10%, with a difference of 0.05% very small. The Correlation value, which is a measure of two variables that are linearly connected (meaning that both change together at a constant rate), is 99.51%, it can be said that the two data have a perfect or very strong relationship and are supported by the Cronbach's alpha calculation value of 1 which describes the same relationship. At the same time, the Relative Standard Error (RSE) is 1.95%. So from the results of the Descriptive Statistical Analysis above the value of the measurement results with the Prototype Ultrasonic Surface Roughmeter measuring instrument can be said to be valid and correct.

The results of the study showed that the "Ultrasonic Surface Roughmeter" prototype had high accuracy with a correlation level of 99.51% compared to the standard tool, the Gap Man Working Profilometer, and a confidence level of 97.05%. The Cronbach's alpha value of 1.0 indicated very good internal consistency, with an average measurement difference of 3.11%. This shows that the prototype can provide reliable measurement results for the International Roughness Index (IRI) on road surface conditions.

When compared to previous studies that also examined road surface roughness measuring tools, such as those conducted by (Alhasan, 2015b), this study has comparable results in terms of accuracy and consistency. Previous studies used expensive geophones and accelerometers, while this study succeeded in developing an alternative tool with a more economical but still accurate ultrasonic sensor. (Alhasan, 2015b) showed that expensive road surface roughness measuring tools can provide a high level of accuracy but are difficult to access by many parties. This study offers a cheaper solution while maintaining accuracy standards that can be compared with conventional tools.

In addition, in a study by (S.-L. Chen et al., 2020), which used a profilometer as a standard measurement tool, the measurement error rate generally ranged from 2-5% in calculating IRI. The results of this prototype, which had an average measurement difference of around 3.11%, were within the acceptable error range according to the standards used in these studies. This strengthens the validity of the "Ultrasonic Surface Roughmeter" prototype as an alternative measurement tool with a lower cost without reducing the accuracy of the results.

CONCLUSION

This research was successful and developed a prototype of the "Ultrasonic Surface Roughmeter" as an alternative tool to measure road surface roughness (IRI) with a high level of accuracy comparable to more expensive standard tools, such as the Gap Man Working Profilometer. With a correlation level of 99.51% and a Cronbach's alpha value of 1.0, this prototype showed very good internal consistency and a confidence level of 97.05%. The average measurement difference of 3.11% between the prototype and the standard tool was within the acceptable error range according to previous research standards. This shows that this prototype can be relied on as a tool for road evaluation and maintenance.

The use of economical ultrasonic sensors in this prototype allows wider access to road roughness measurement technology in various regions, especially in developing countries or areas with budget constraints. This prototype provides opportunities for related parties, such as local governments and road contractors, to adopt more cost-effective but still accurate tools in assessing road conditions.

REFERENCES

Alhasan, A. A. (2015a). *Quantifying Road Roughness: Multiresolution And Near Real-Time Analysis*. Iowa State University.

Alhasan, A. A. (2015b). *Quantifying Road Roughness: Multiresolution And Near Real-Time Analysis*. Iowa State University.

Alhasan, A. A., White, D. J., De Brabanter, K., Vennapusa, P., Aggarwal, R., Westport, C., & Ashlock, J. (N.D.). *Quantifying Road Roughness: Multiresolution And Near Real-Time Analysis*.

ASTM International. (2003). Standard Practice For Computing International Roughness Index Of Roads From Longitudinal Profile Measurements. *ASTM International*, *E 1926*(98), 1–18. Www.Astm.Org,

Bahaaeldin Hassan, S. (2021). *Calibration Of IRI-Based PSI Equation Using Updated Quarter-Car Calibration Parameters*. Https://Researchrepository.Wvu.Edu/Etd

Baladi, & GY. (1991). Pavement Condition Index - Remaining Service Lite. *Novak, EC*, 63–90. Https://Doi.Org/10.1520/STP177955

Bulaha, N. (2018). Calculations Of Surface Roughness 3d Parameters For Surfaces With Irregular Roughness. *Engineering For Rural Development*, *17*, 1437–1444. Https://Doi.Org/10.22616/Erdev2018.17.N256

Chen, S. L., Lin, C. H., Tang, C. W., Chu, L. P., & Cheng, C. K. (2020). Research On The International Roughness Index Threshold Of Road Rehabilitation In Metropolitan Areas: A Case Study In Taipei City. *Sustainability (Switzerland)*, *12*(24), 1–19. Https://Doi.Org/10.3390/Su122410536

Chen, S.-L., Lin, C.-H., Tang, C.-W., Chu, L.-P., & Cheng, C.-K. (2020). Research On The International Roughness Index Threshold Of Road Rehabilitation In Metropolitan Areas: A Case Study In Taipei City. *Sustainability*, *12*(24), 10536.

Dewi Asri Anugrah. (2021). *Analisa Penilaian Kondisi Jalan Raya Dengan Metode Surface Distress Index (SDI) Dan Present Service Ability Index (PSI) Studi Kasus : Duri Kecamatan Mandau*. Universitas Islam Riau.

Direktorat Jenderal Bina Marga. (2011). *Direktorat Jenderal Bina Marga, Survei Kondisi Jalan Untuk Pemeliharaan Rutin*.

Golov, E., Evtyukov, S., Protsuto, M., Evtyukov, S., & Sorokina, E. (2022). Influence Of The Road Surface Roughness (According To The International Roughness Index) On Road Safety. *Transportation Research Procedia*, *63*, 999–1006. Https://Doi.Org/10.1016/J.Trpro.2022.06.099

Pekerjaan Umum Indonesia. (1995). *Manual Pemeliharaan Rutin Untuk Jalan Nasional Dan Jalan Propinsi Jilid Ii : Metode Perbaikan Standar*. Https://Pu.Go.Id/Pustaka/Biblio/Manual-Pemeliharaan-Rutin-Untuk-Jalan-Nasional-Dan-Jalan-Propinsi-Jil...

Pemerintah Republik Indonesia. (2004). *Undang-Undang Republik Indonesia Nomor 38 Tahun 2004 Tentang Jalan*.

Prijo Sadewo. (1995). *Manajeman Pemeliharaan Jalan*. Institut Teknologi Sepuluh Nopember.

Richard W. V. Uguy, & Vanda S. Rompis. (2021). Penentuan Jenis Pemeliharaan Jalan Dengan Menggunakan Metode Bina Marga (Studi Kasus: Ruas Jalan Kelurahan Tondangow Kecamatan Tomohon Selatan). *Jurnal Ilmiah Realtech*, *17*(2), 34–38.

Sayers, M. M. (1995). On The Calculation Of International Roughness Index From Longitudinal Road Profile. *Committee On Surface Properties-Vehcle Interaction*, *1501*, 1–12. Https://Trid.Trb.Org/View/452992#:~:Text=IRI%20is%20calculated%20from%20a,Index%20with%20units%20of%20slope.

Sayers, M. W., Gillespie, T. D., & Paterson, W. D. 0. (1986a). *Guidelines For Conducting And Calibrating Road Roughness Measurements*.

Sayers, M. W., Gillespie, T. D., & Paterson, W. D. O. (1986b). *Guidelines For Conducting And Calibrating Road Roughness Measurements*. World Bank.

SNI 03-3426-1994. (1994). *Tata Cara Survei Kerataan Permukaan Perkerasan Jalan Dengan Alat Ukur Kerataan NAASRA*. Https://Binamarga.Pu.Go.Id/Index.Php/Nspk/Detail/Sni-03-3426-1994-Tata-

Cara-Survai-Kerataan-Permukaan-Perkerasan-Jalan-Dengan-Alat-Ukur-Kerataan-Naasra

Suwardo, & Heru Budi Utomo. (2020). Pengukuran Dan Perekaman Data Ketidakrataan Perkerasan Jalan Dengan Sensor Ultrasonik Pada Rolling Straight Edge. *Jurnal Aplikasi Teknik Sipil*, *18*(2), 295–306. Http://Iptek.Its.Ac.Id/Index.Php/Jats

Transportation Association Of Canada. (2006). *Performance Measures For Road Networks: A Survey Of Canadian Use*.

Wahyu, E., Pratikso, & Siegfried. (2023). Typical Roughness Values From Geophone-Based Roughness Meter Data For Evaluating Road Functional Performance. *International Conference On Engineering Science, Innovation Technology, And Sustainability 2023 (ICESIT 2023) Will Be Held On 26th-27th October 2023 At Yogyakarta, Indonesia*, 1–11. Https://Drive.Google.Com/Drive/Folders/1kybvd-Hhx3oqZBY9zCvlV4z9UY494GBA

Yoga Triardhana, Bandi Sasmito, & Firman Hadi. (2021). Identifikasi Kerusakan Jalan Menggunakan Metode Deep Learning (DL) Model Covolutional Neural Networks (CNN). *Jurnal Geodesi Undip Juli*, *10*.