International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

https://gssrr.org/index.php/JournalOfBasicAndApplied/index

Road Performance Relationship Analysis Using PCI and IRI Method on Tukum East Ring Road

Nillam Yahaya Azhary[a], Anik Ratnaningsih[b*], Abdur Rohman[c]

[a,b,c]*Department of Civil Engineering, Faculty of Engineering, Jember 68121, Indonesia*
[a]*Email: yahaya.azhary@gmail.com*, [b]*Email: anik.teknik@unej.ac.id*
[c]*Email: abdur@unej.ac.id*

Abstract

The road performance management system in pavement maintenance is based on the existing condition of the road, both functionally and structurally. Various road performance indices were developed to determine the quality of asphalt pavement and road maintenance strategies, such as the Pavement Condition Index (PCI) and International Roughness Index (IRI) methods which provide an assessment of road performance conditions in terms of damage and roughness. The main objective of this study is to analyze the relationship between road performance using the Pavement Condition Index (PCI) and the International Roughness Index (IRI). Based on the results of the two methods, the researcher processed the data by developing linear and non-linear regression models to obtain the best relationship model for the East Ring Line of Lumajang Regency. The data shows that on the Lumajang Regency East Ring Road, the average PCI value is 26.76 with the poor category, the IRI value is 7.92 with the poor category. One of the sections on the East Ring Road section, namely the JLT Tukum section with a segment length of 5.000 m, has a PCI value of 49 which is included in the poor category and the IRI value for the JLT Tukum section is 5.6 which is included in the fair category. Based on the analysis results, the best model for the Tukum East Ring Road is a non-linear exponential regression model with the equation $IRI = 200 (1 - 0.02)^{PCI}$ and a value of $R^2 = 0.94$.

Keywords: road; road damage; Pavement Condition Index (PCI); International Roughness Index (IRI); relationships.

Received: 5/20/2023
Accepted: 6/28/2023
Published: 7/8/2023

----

* Corresponding author.

1. Introduction

The implementation of a pavement management system is an important part of producing comfortable and safe road infrastructure [1]. The determination of the pavement maintenance management system is based on the existing condition of the road pavement both functionally and structurally. Structural condition is the ability of the road surface to withstand vehicle loads, and functional condition is the ability of the road surface to provide good serviceability, comfort and safety for its users.

Pavement condition evaluation is considered as one of the main components of pavement design and rehabilitation in a pavement management system [2]. Various road performance indices have been commonly used to determine the quality of asphalt pavement and road maintenance strategies, such as the Pavement Servicebility Index (PSI), Pavement Condition Index (PCI), and International Roughness Index (IRI) [3]. The PCI method is the most widely used index for assessing pavement conditions [4]. PCI is widely accepted to describe the overall condition of the pavement surface of a road section [2]. However, its implementation takes a long time and is not suitable for busy traffic because it causes traffic problems [5]. Apart from the PCI method, the IRI method is also often used to evaluate road conditions [6]. This method can only record the value of the flatness of the road surface passed by vehicles which indicates the level of comfort for road users, so it cannot describe the overall condition of road damage [7].

In addition, there is another regression method regarding the relationship between IRI and PCI values in Francisco that was developed by Dewan and Smith [8]. Road damage failure is a consideration in modeling, such as alligator cracks, block cracks, longitudinal cracks, transverse cracks, groove cracks, and weathering. The results of this study indicate that modeling with linear regression has a good value, with the formulation of linear regression 1, namely:

$$IRI = 0.0171(153 - PCI)(R^2 = 0.53) \qquad (1)$$

The relationship between IRI and road damage is presented by Mactutis and colleagues on his research [9]. In this connection, the value of IRI depends on the type of damage that occurs. Damage that is taken into account includes fatigue cracks (alligator and longitudinal cracks) and rutting, while other pavement damage is not taken into account. IRI values ranged between 0.825 and 3.454 the majority between 0.825 and 1.7. This study shows the effect of the type of fatigue crack damage on IRI, while the type of rutting damage has no effect on IRI.

The linear regression model for estimating IRI based on the level of road damage was developed by Sandra and Sarkar [10]. The types of damage considered in the estimation of IRI values are cracks, holes, rutting, raveling, and patching. The results of this study indicate that the road with the greatest impact on the model on Indian roads is potholed and decomposed roads with an R^2 value of 0.986.

Elhadidy and colleagues discusses the relationship model between PCI and IRI. As a result, the best relationship was found between PCI and IRI with a coefficient of determination (R2) of 0.995 [4].

The main objective of this research is to investigate the relationship between the Pavement Condition Index

(PCI) and the International Roughness Index (IRI). To achieve this goal, the location of the Tukum East Ring Road, Lumajang Regency, which is an alternative route connecting Jember Regency and Surabaya City, was chosen to be the research review. IRI data and road damage for several types of damage are supporting parameters for analyzing the relationship between the PCI and IRI. The distinctive point of this study is the analysis and comparison of the relationship between the PCI and IRI carried out on the Tukum East Ring Road section, Lumajang Regency by considering several factors.

The difference between this study and previous studies lies in the modeling of the relationship between IRI and PCI. Previous studies have analyzed the relationship between IRI and PCI using one model (linear or nonlinear) without dividing the data into several segments. In this study, the relationship between IRI and PCI was investigated by comparing several features and models, namely Exponential Regression, Power, Linear, and Dewan & Smith Modeling.

2. Methodology

2.1. Study Location

The research location is on the East Ring Road section of Tukum, Lumajang Regency with a length of 5.500 m. The East Ring Road (JLT) of Lumajang Regency is an important access that connects the North Lumajang section with the South Lumajang section and connects Lumajang Regency with Jember Regency. The East Ring Route is an alternative that is often used by motorists, including trucks with heavy loads, to pass through Lumajang Regency without going through urban areas. Figure 1 shows the location used in this study.

Figure 3: JLT Tukum linear regression.

2.2. Data Collection

The data needed in the analysis of the relationship between the PCI and IRI on the Tukum East Ring Road section of Lumajang Regency was obtained through the Public Works and Spatial Planning Office of Lumajang

Regency. As for some of the data needed, namely the Lumajang Regency road map which includes administrative data and road classification, IRI (International Roughness Index) data, IRI (International Roughness Index) values which are roughness indexes through direct measurements in the field using the NAASRA (National Association Of Australians) tool. State Road Authorities), and road damage data in the form of dimensions of each road damage, such as curling, grooves, subsidence and alligator skin cracks. Road damage data obtained from survey results in the field.

2.3. Pavement Condition Index (PCI)

The Pavement Condition Index (PCI) is a method developed by the U.S Army Corp of Engineers which is used to assess road pavement conditions [11]. PCI is based on the results of a visual condition survey [12]. The steps that must be taken in determining the PCI value include determining the type of damage, the severity of the damage, the amount or density of damage [13, 14]. PCI is a numeric index whose value ranges from 0 to 100.

Table 2: PCI value index.

PCI Value	Ranking	Category
85 – 100	1	Excellent
70 – 85	2	Very good
55 – 70	3	Good
40 – 55	4	Fair
25 – 40	5	Poor
10 – 25	6	Very poor

2.4. International Roughness Index (IRI)

The International Roughness Index (IRI) is an unevenness parameter that is calculated from the cumulative amount of rise or fall of the surface in the direction of the longitudinal profile divided by the distance/length of the surface being measured [15]. There are several tools that can be used to obtain IRI values, including using the NAASRA Roughmeter [16].

Table 2: IRI value index.

IRI Value	Ranking	Category
0 – 2	1	Very good
2 – 4	2	Good
4 – 6	3	Fair
6 – 8	4	Poor
8 – 10	5	Very poor

2.5. Regression Analysis

Regression is a measure of the relationship between two or more variables which is expressed in the form of a relationship/function. A clear separation is needed between the independent variable and the dependent variable, usually symbolized by x and y. In regression there must be a determined variable and a determining variable or in other words, there is a dependence between one variable and another variable. The two variables in the regression are usually causal or causal, that is, they influence each other. Thus, regression is a form of a particular function between the dependent variable y and the independent variable x or it can be stated that regression is a function y = f(x). The form of regression depends on the function or equation it has [17].

2.6. Residual Sum of Squares (RSS)

Residual Sum of Squares (RSS) is the sum of the squares of the residuals (the predicted deviation from the actual empirical value of the data) used to measure the difference between the data and the estimated model in linear regression [18]. A good RSS value is one that is close to 0 [19].

2.7. Root Mean Squared Error (RMSE)

Root Mean Squared Error (RMSE) is the average value of the sum of the squared errors and can also express the size of the size of the error produced by an estimation model. If the RMSE value is low, it indicates that the variation in the value obtained by an approximate model is close to the variation in the observed value [20]. The prediction model is said to be the best if the value and RMSE are 0 [21].

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \qquad (2)$$

2.8. Mean Absolute Error (MAE)

Mean Absolute Error (MAE) is one of the methods used to measure the accuracy of forecasting models. The MAE value shows the average absolute error between the forecasting/prediction results and the real value. MAE calculates the average error by giving the same weight to all data intuitively [22].

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |f_i - y_i| \qquad (3)$$

3. Results and Discussion

3.1. IRI and PCI Values

IRI and PCI values are two benchmarks for assessing pavement performance conditions. IRI and PCI have different levels of variation in values. The range that is owned on IRI is relatively smaller than the range of values on PCI. The recapitulation of IRI and PCI values can be seen in Figure 2.

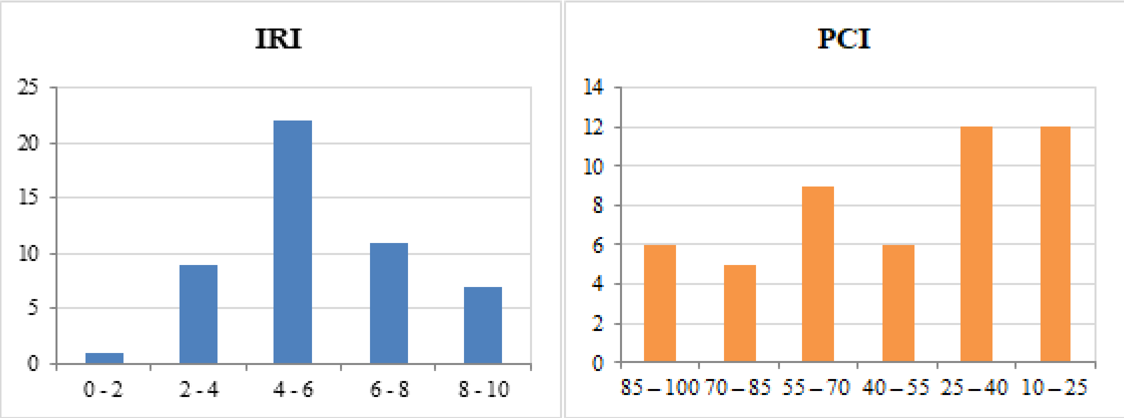

Figure 2: Recapitulation of IRI and PCI values.

The Tukum East Ring Road section has an average PCI score of 49 which is included in the poor category. While the IRI value on the Wonorejo East Ring Road section has an average value of 4.1 which is included in the medium category. To find out the comparison between road conditions based on the PCI method and road conditions based on the IRI method can be seen in Table 3.

Table 3: IRI value index.

Section	Parameter	Number of Section	Unit	Mean	Min	Max
JLT Tukum	PCI	50	m/km	49	10	96
	IRI	50	m/km	5.6	2	10

3.2. Relationship of IRI and PCI Values

The results of the evaluation of road conditions based on the PCI value and the IRI value, a statistical test analysis was carried out to determine the relationship between the road damage value (PCI) and the road unevenness value (IRI). The statistical test analysis was carried out on IRI and PCI data using the 5 models that have been developed. As can be seen in Figure 3, this is the distribution of the initial data in modeling the relationship between IRI and PCI values.

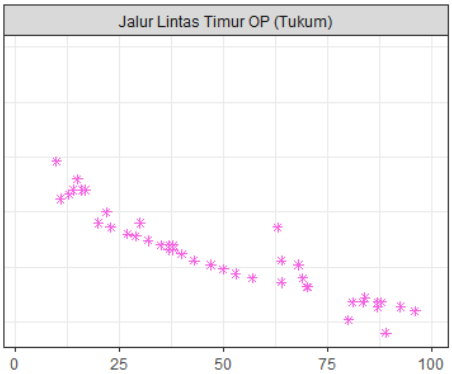

Figure 3: JLT Tukum linear regression.

The relationship model between IRI and PCI values was developed through 5 models, of which 3 models were non-linear regression and 2 other models were linear regression as shown in Table 4.

Table 4: Non-linear regression models.

Non-linear regression	Equation Models
Geometric	$y = a \cdot e^{(b * x)}$
Exponen	$y = a (1 + b)^x$
Power	$y = a \cdot 1 / (x^b)$
Linear	$y = 8{,}1 – (0.05\ x)$
Dewan & Smith	$y = 0{,}0171 (153 – x)$

The coefficient that best fits the data can be obtained from the initial estimated value of a and b. The tool used in determining the initial estimated value of a and b is using the desmos graph calculator. Furthermore, by using the nls function with the Gauss Newton algorithm, the a and b values that best fit the data can be obtained which can be seen in Table 5.

Table 5: a and b coefficient.

a	b	Equation
10	– 0,014	$IRI = 10 \cdot e^{(– 0{,}014 * PCI)}$
200	– 0,02	$IRI = 200 (1 – 0{,}02)^{PCI}$
860	1,8	$IRI = a \cdot 1 (PCI^b)$
8,1	– 0,05	$IRI = 8{,}1 – (0{,}05\ PCI)$

Based on the regression results on the Tukum East Ring Road section, the estimated value is negative.

This shows that the greater the PCI value on the road section, the smaller the IRI or roughness value that occurs on the road segment.

Cross validation is data resampling that uses different parts of the data to test and train the model in different iterations. In this analysis using 10 data divisions. The following are the results of the RSS for each model on the Tukum East Ring Road section which are shown in Table 6.

Table 6: RSS results.

Section	Models	RSS
JLT Tukum	Model 1	1,51
	Model 2	1,46
	Model 3	2,16
	Model 4	1,75
	Model 5	134,12

Based on the RSS value that has been obtained, the smallest RSS value is selected to proceed to the test using previously sorted test data. On the Tukum East Ring Road section, model 2 was chosen with an average RSS of 1.46. After selecting the model with the smallest average RSS value, then proceed with testing using the test data that was separated at the beginning.

3.3. Model Validation

It has been mentioned that 20% random data is set aside at the start of the modeling process. The randomization of the selected data is set aside for the model validation process. Furthermore, the predicted IRI values or modeling results are compared statistically with the data IRI values. Validation is carried out by considering the RSS, RMSE, MAE and R^2 values, where the concept of validation is the value of the difference between the IRI data value and the predicted or modeled IRI value. Table 7 is the result of the recapitulation of the accuracy value of non-linear regression modeling using exponential equations on the JLT Tukum segment and in Figure 4 is a data plot of the distribution of IRI values as a result of modeling or prediction with IRI values. The R^2 value in table 9 shows that the predictor variable x (PCI) is able to explain the response of the variable y (IRI) of 0.94.

Table 7: Results of non-linear regression modeling.

Ruas	Equation	RMSE	MAE	R^2
JLT Tukum	$IRI = 200\ (1 - 0{,}02)^{PCI}$	0,6031	0,4132	0,94

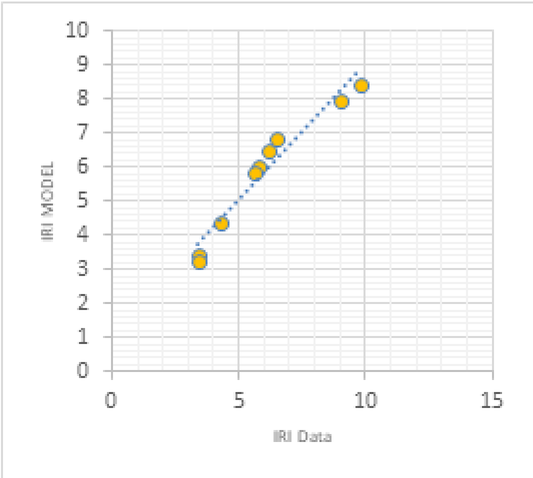

Figure 4: IRI model with IRI data.

3.4. Analysis

As mentioned earlier, the development of this research is in data processing carried out in several sections and the development of IRI and PCI relationship models in the form of Exponential, Power, Exponential, Linear Regression and Equation of Results of previous researchers. Research conducted by (Dewan & Smith, 2005) (Sandra & Sarkar, 2013) (Elhadidy and colleagues 2021) uses the Linear relationship model. The estimated value obtained in the regression model is negative. This shows that the greater PCI value on the road section, the smaller IRI or roughness value that occurs on the road section. In some ranges, PCI and IRI values have no acceptable relationship. In the data collected in this study, the majority of the PCI data range according to IRI 2-4 is 85 - 100.

At JLT Tukum, Lumajang Regency uses RSS per section which states the value of the difference between the

IRI model results and the IRI data. Based on the best RSS value of the exponential model, the smallest RSS value is used as the basis for selecting the best model and model validation. Model validation reviews several values, namely RMSE, MAE and R2. The modeling results state that the average value of the sum of the squared errors is 0,603, the average error error is 0,413 and the effect of the PCI value on the IRI value is 0,94. The relationship modeling plot using IRI = 200(1-0,02)PCI between IRI and PCI can be seen in Figure 5. Several things affect the IRI and PCI relationships on each section, namely:

- Classification of the type of road chosen affects the relationship between IRI and PCI values, research (Dewan & Smith, 2005) predicts IRI and PCI values without considering the type of road classification, only considering the type of damage that occurs.
- The influence of the type of pavement failure in each area has a low impact on roughness. Examples of failure or damage in question are edge cracks, because they can increase the level of damage but do not provide a high degree of roughness.
- The range of IRI and PCI used is limited to the regulations of the Ministry of Public Works of Highways, further analysis is needed on the need for appropriate IRI and PCI ranges.

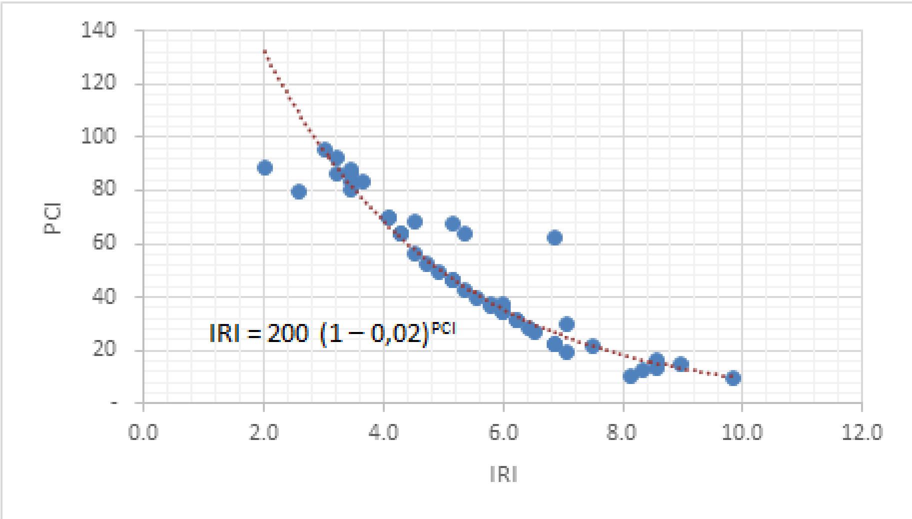

Figure 5: Relationship between IRI and PCI.

4. Conclusion

The PCI value considers the type of pavement damage or failure on each road section and the IRI value is obtained based on the road roughness obtained through the NAASRA tool. Each road section has different IRI and PCI values due to the different types of pavement damage that occurs in each section. Aiming as a reference in making decisions related to maintenance and repair of road pavements, this research was conducted to develop the relationship between two pavement qualities, namely IRI and PCI. The relationship model for IRI and PCI uses the Tukum East Ring Road section, Lumajang Regency, which was obtained through the Public Works and Spatial Planning Office of Lumajang Regency. The PCI value for the JLT Tukum section is 49 which is included in the poor category, while the IRI value for the JLT Tukum section is 5.6 which is in the fair category. Judging from the edge cracks on the road, it can be seen that the higher the edge crack value, the higher the PCI value obtained and the lower the IRI value.

The exponential non-linear regression relationship model has the highest correlation value with the fewest errors compared to other linear and non-linear regression models. Therefore, in terms of the RMSE, MAE, and R^2 values, exponential regression was chosen as the best model for connecting IRI and PCI in thes JLT Tukum section. Based on the results of non-linear regression analysis, the equations obtained from the two methods are IRI = 200 $(1 - 0{,}02)^{PCI}$ and the value of R^2 = 0.94. The meaning of the determination value obtained is the magnitude of the accuracy of the PCI relationship modeling on the IRI value of 0.94.

Suggestions in future research need to do a thorough review of the variables that affect road damage such as weather, traffic density and road pavement implementation methods to produce more accurate relationships and results.

5. Recommendation

This research was conducted on several sections of the Lumajang East Ring Road with the same classification. It does not consider other variables that affect road damage, such as weather factors, implementation methods, and traffic density. Recommendations for future research need to compare the IRI and PCI relationships on several sections with different road classifications and a thorough review of variables that affect road damage, such as weather, traffic density, and road pavement implementation methods, to produce a more accurate IRI and PCI relationship.

References

[1] H. Pérez-Acebo, A. Linares-Unamunzaga, E. Rojí, and H. Gonzalo-Orden, “IRI performance models for flexible pavements in two-lane roads until first maintenance and/or rehabilitation work,” *Coatings*, vol. 10, no. 2, 2020, doi: 10.3390/coatings10020097.

[2] A. Issa, H. Samaneh, and M. Ghanim, “Predicting pavement condition index using artificial neural networks approach,” *Ain Shams Eng. J.*, vol. 13, no. 1, p. 101490, 2022, doi: 10.1016/j.asej.2021.04.033.

[3] S. Adeli, V. Najafi Moghaddam Gilani, M. Kashani Novin, E. Motesharei, and R. Salehfard, “Development of a Relationship between Pavement Condition Index and International Roughness Index in Rural Road Network,” *Adv. Civ. Eng.*, vol. 2021, 2021, doi: 10.1155/2021/6635820.

[4] A. A. Elhadidy, S. M. El-Badawy, and E. E. Elbeltagi, “A simplified pavement condition index regression model for pavement evaluation,” *Int. J. Pavement Eng.*, vol. 22, no. 5, pp. 643–652, 2021, doi: 10.1080/10298436.2019.1633579.

[5] L. O. Kalengkongan, J. E. Waani, and S. Y. R. Rompis, “Model Hubungan Antara Ketidakrataan

Permukaan Jalan dengan Nilai Kerusakan Permukaan Jalan Pada Ruas Jalan Nasional di Kota Manado (Stusi Kasus : Ruas Jalan Batas Kota Manado - Tomon dan Jalan Mongosidi)," *J. Ilm. Media Eng.*, vol. 11, no. 2, pp. 135–144, 2021, [Online]. Available: https://ejournal.unsrat.ac.id/index.php/jime/article/view/36668.

[6] A. Sharma, S. N. Sachdeva, and P. Aggarwal, "Predicting IRI Using Machine Learning Techniques," *Int. J. Pavement Res. Technol.*, vol. 16, no. 1, pp. 128–137, 2023, doi: 10.1007/s42947-021-00119-w.

[7] O. G. Dela Cruz, C. A. Mendoza, and K. D. Lopez, "International Roughness Index as Road Performance Indicator: A Literature Review," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 822, no. 1, 2021, doi: 10.1088/1755-1315/822/1/012016.

[8] S. A. Dewan and R. E. Smith, "Valuing Pavement Network Assets and Use of Values as Decision Supports," *J. Infrastruct. Syst.*, vol. 11, no. 4, pp. 202–210, 2005, doi: 10.1061/(asce)1076-0342(2005)11:4(202).

[9] J. A. Mactutis, S. H. Alavi, and W. C. Ott, "Investigation of relationship between roughness and pavement surface distress based on WesTrack project," *Transp. Res. Rec.*, no. 1699, pp. 107–113, 2000, doi: 10.3141/1699-15.

[10] A. K. Sandra and A. K. Sarkar, "Development of a model for estimating International Roughness Index from pavement distresses," *Int. J. Pavement Eng.*, vol. 14, no. 8, pp. 715–724, 2013, doi: 10.1080/10298436.2012.703322.

[11] R. Imam, Y. Murad, I. Asi, and A. Shatnawi, "Predicting Pavement Condition Index from International Roughness Index using Gene Expression Programming," *Innov. Infrastruct. Solut.*, vol. 6, no. 3, pp. 1–12, 2021, doi: 10.1007/s41062-021-00504-1.

[12] H. Amelia Setiaputri, M. Isradi, A. Irfan Rifai, A. Mufhidin, and J. Prasetijo, "Analysis Of Urban Road Damage With Pavement Condition Index (PCI) And Surface Distress Index (SDI) Methods," *ADRI Int. J. Sci. Eng. Technol.*, vol. 6, no. 01, pp. 10–19, 2021, doi: 10.29138/ijset.v6i01.61.

[13] Paikun, E. Suminar, A. Irawan, and S. Bahri, "DETERMINING ROAD HANDLING ACCORDING TO THE LEVEL OF DAMAGE USING SURFACE DISTRESS INDEX (SDI) METHOD (Case study on Jl. Merdeka 1 Sukabumi City)," *ASTONJADRO J. Rekayasa Sipil*, vol. 10, no. 1, pp. 135–149, 2021, [Online]. Available: http://150.107.142.43/index.php/ASTONJADRO/article/view/5471/0.

[14] M. F. Romadhon, D. A. Susanto, S. Anugrahamdani, and R. R. Sunhadji, "Analisis kondisi kerusakan jalan pada ruas jalan Kadudampit dengan metode Pavement Condition Index (PCI)," *J. TESLINK Tek. Sipil dan Lingkung.*, vol. 3, no. 2, pp. 84–94, 2021, doi: 10.52005/teslink.v3i2.77.

[15] M. A. Rahman, H. Arifin, and B. O. Sowolino, "Perbandingan Metode International Roughness Index

Dengan Pavement Condition Index Untuk Penentuan Kondisi Jalan Nasional Di Kota Wamena (Studi Kasus : Ruas Jalan Wamena – Habema),” *Rang Tek. J.*, vol. 5, no. 1, pp. 1–7, 2022, doi: 10.31869/rtj.v5i1.2702.

[16] D. A. Azhar, B. Prasetyo, and A. Budiharjo, “Analisis Hubungan Pavement Condition Index (PCI) dan Surface Distress Index (SDI) Dengan International Roughness Index (IRI),” 2019, [Online]. Available: http://repository.untad.ac.id/2454/.

[17] R. Kurniawan, *Analisis Regresi*. Prenada Media, 2016.

[18] L. M. Samryn, “Perbandingan Pengaruh Arus Kas dari Aktivitas Investasi terhadap Rasio Kecukupan Modal Bank Umum Indonesia dan Malaysia,” *J. Bisnis dan Manaj.*, vol. 27, no. 1, pp. 57–71, 2022.

[19] A. E. Syahputra, Y. Fanani, and S. H. Yuwanto, “Estimasi Sumberdaya dan Cadangan Dengan Metode Ordinary Kriging pada Blok Eksplorasi Cahaya Prima Kausa di PT. Cinta Jaya (Gasing Grub) Desa Tapunggaya, Kecamatan Molawe, Kabupaten Konawe Utara, Provinsi Sulawesi Tenggara,” *J. Geol. Sriwij.*, vol. 2, 2022.

[20] F. Hafiz *et al.*, “Model Lapisan Geologi Teknik Permukaan Menggunakan Metode Gelombang Geser di Kecamatan Darul Imarah Aceh Besar,” vol. 4, pp. 260–266, 2022.

[21] F. A. Chaidir and N. Dewanti, “ANALISA PERBANDINGAN DATA PASANG SURUT DENGAN METODE KOEFISIEN KORELASI DAN RMSE ANTARA DATA IOC - SEALEVELMONITORING DAN DATA PROGRAM NAOTIDE,” no. November, pp. 36–41, 2022.

[22] A. A. Suryanto, “Penerapan Metode Mean Absolute Error (Mea) Dalam Algoritma Regresi Linear Untuk Prediksi Produksi Padi,” *Saintekbu*, vol. 11, no. 1, pp. 78–83, 2019, doi: 10.32764/saintekbu.v11i1.298.