Jurnal Sainstech Nusantara
https://nusantarajournal.id/sainstech
Vol. 2 No. 3 (2025) 46-57
ISSN: 3063-0657

Accuracy Assessment of Railway Track Inspection Equipment 'Void Meter' Based on the Internet of Things

Wahyu Tamtomo Adi [1], Bagas Risnanto Nugroho[1], Hana Wardani Puruhita[1]

[1]Construction And Railway Technology, Politeknik Perkeretaapian Indonesia Madiun, Indonesia Jl. Tirta Raya Pojok Nambangan Lor,63121-East Java, INDONESIA

Article Info

Article history:

Received 10 March, 2025
Revised 18 May, 2025
Accepted 04 July, 2025

Abstract

Dynamic skilu caused by ballast voids is one of the main causes of train derailments in Indonesia. Early detection of this condition still relies on measurement trains, which have limited inspection intervals. This study aims to test the accuracy of the third-generation void meter based on the Internet of Things (IoT), which has been redesigned to enhance the precision of measuring ballast voids, train speed, and rail temperature. The research methods include the collection of primary and secondary data, field testing of the device, and statistical analysis. Analysis was conducted using standard deviation tests, ANOVA, the Mann–Whitney test, and MAPE. Test results showed that the system can display data in real-time through the Blynk and ThingSpeak platforms and provide automatic notifications when measurement values exceed tolerance limits. The standard deviation of the device is lower than that of conventional devices, MAPE for all parameters is <10%, and the results of the ANOVA and Mann–Whitney tests show no significant differences between data groups. Thus, the third-generation void meter has proven to have high accuracy and consistency, making it suitable for continuous railway track inspections. Additionally, the void meter has been proven to be 59.70% more cost-effective than the densometer.

Keywords: Void Meter, Internet of Things, Dynamic Skilu, Ballast Void Measurement, Data Accuracy.

***Corresponding Author:**

Name Wahyu Tamtomo Adi
Email: tamtomo@ppi.ac.id

1. Introduction

Damage to railway geometry, particularly undetected dynamic skilu, is the main cause of train derailments in Indonesia [1]. According to a report by the National Transportation Safety Committee (KNKT), 69% of railway accidents are caused by infrastructure damage, with derailments being the most prevalent type of accident, accounting for 73% of total incidents between 2016 and 2020 [2][3].

DOI: https://doi.org/10.71225/jstn.v2i3.115

Dynamic track defects, caused by voids beneath the rail sleepers, can trigger excessive vertical deflection when trains pass over them, affecting track stability [4] [5].

Currently, dynamic skilu detection still relies on measurement trains with limited inspection intervals, leaving the potential for damage to go unnoticed between inspection cycles [6] [7]. Therefore, to minimise such accidents, a preventive measure that can be operated continuously is needed to prevent similar incidents from recurring [8]. Therefore, mitigation efforts against potential accidents caused by dynamic skilu require an inspection system that can operate continuously and in real-time [9]. In this case, an inspection device in the form of a void meter is needed, which can precisely detect ballast voids, allowing for the determination of whether dynamic skilu exceeds the damage tolerance limit when the train is crossing the rail line [10] [11].

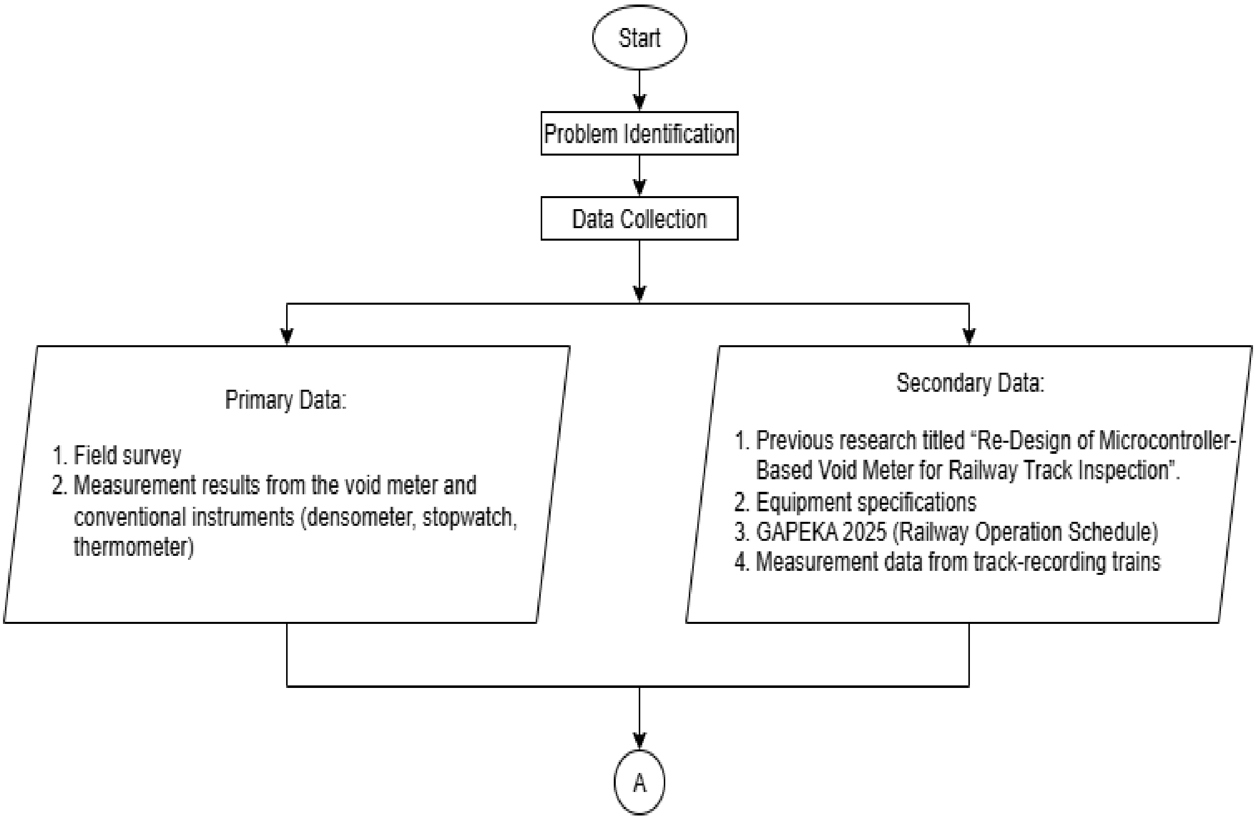
The second-generation void meter, designed in previous research, still shows limitations, particularly in terms of measurement accuracy for ballast voids and train speed [12]. This improvement impacts the reliability of the device in precisely detecting dynamic skilu. For the third generation, improvements were made to the sensor systems and data integration to produce valid and consistent measurements [13].

This study aims to test the accuracy of the third-generation void meter, which has been redesigned and improved from the previous generation, to ensure reliability and more optimal measurement accuracy. This accuracy test was conducted to ensure the operational feasibility of the device in the field in detecting dynamic skilu on railway infrastructure.

2. Research Method

2.1. Research Flow Chart

This study aims to present the results of accuracy tests on the third-generation void meter based on the Internet of Things. The stages of the study are presented in the following flow chart.



DOI: https://doi.org/10.71225/jstn.v2i3.115

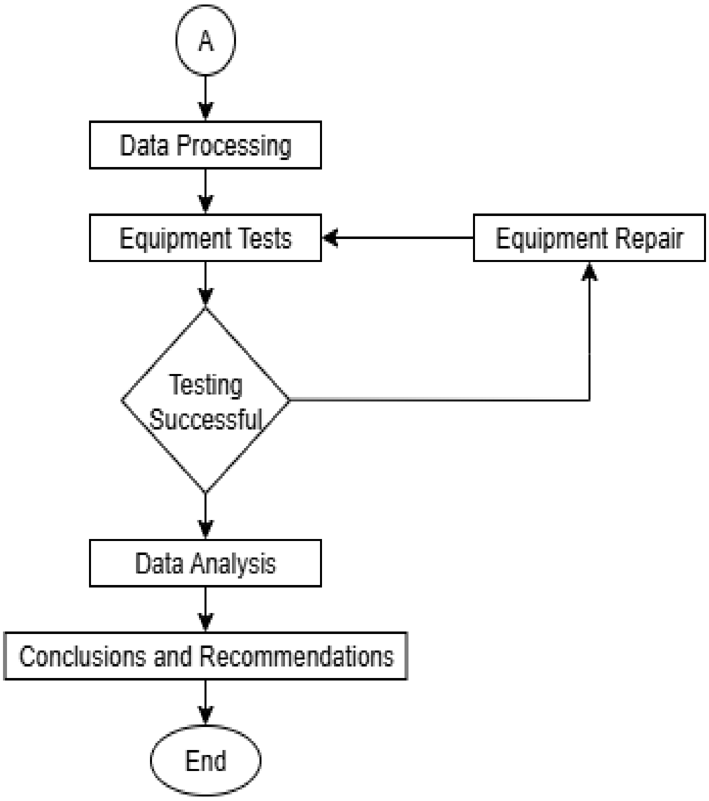


Figure 1. Research Flow Chart

Based on the flow chart in Figure 1, the research stages begin with the process of identifying problems found in the previous generation of void meter, particularly in terms of the accuracy of ballast void measurement and the speed of the train. A redesign of the void meter was conducted using more accurate sensors and integrating the system based on the Internet of Things. The design result was tested on the railway line to determine the accuracy of the new design.

2.2. Data Collection

The data used in this study consists of primary and secondary data.

a. Primary data were collected through field surveys and direct measurements using a third-generation void meter and conventional comparison tools, including a densometer, stopwatch, and thermometer (rail temperature meter).

b. Secondary data includes previous research results related to the microcontroller-based void meter, technical specifications of components, 2025 GAPEKA data, and measurement results from the measuring train used to determine the test location and collect data.

2.3. Data Processing and Equipment Testing

The collected data is then processed to support the equipment testing stage. Testing is carried out to assess the performance of the equipment in accurately generating measurement data on ballast voids and dynamic skilu. If the test results indicate incompatibility with tolerance parameters, a system improvement process is initiated, encompassing mechanical, electronic, and software (firmware) aspects. This testing and improvement cycle is carried out until measurement results that meet reliability criteria are obtained.

2.4. Data Analysis

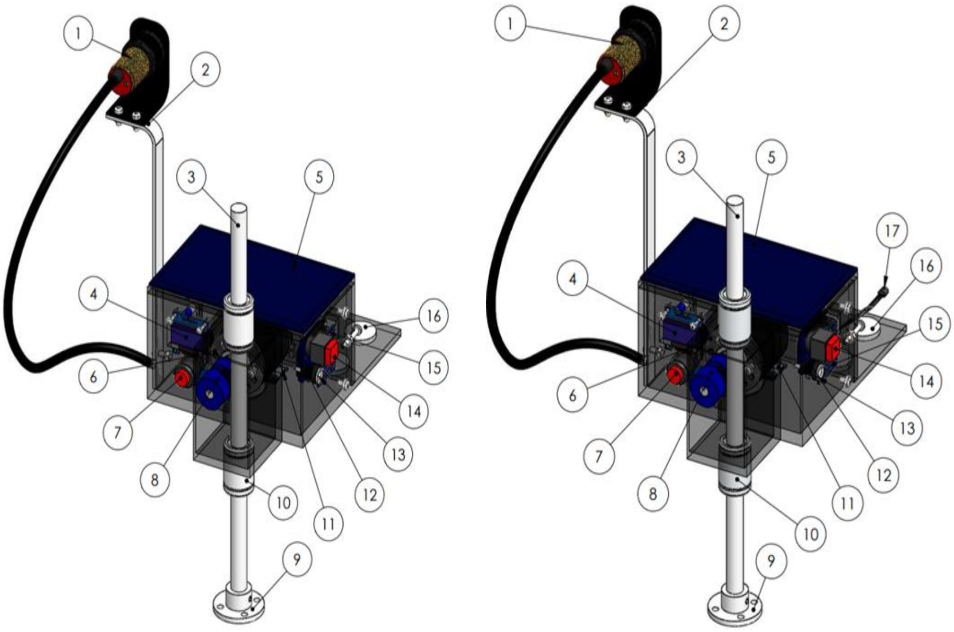
After the equipment testing was declared successful, the data generated was statistically analysed to test its validity, consistency, and accuracy. Several analysis methods were used, including:

a. Standard Deviation Test
   To determine the level of distribution or variation of data relative to the average measurement value [14].
b. ANOVA Test (Analysis of Variance)
   To identify whether there are significant differences between the measurement results of the void meter and the reference instrument across several data groups [14].
c. Mann–Whitney Test
   Used as a non-parametric test when data is not normally distributed, to statistically compare two groups of measurement results [7, 8].
d. MAPE (Mean Absolute Percentage Error)
   Used to measure the accuracy of the device in generating predictive values relative to reference values. A MAPE value <10% is considered to indicate high accuracy [9, 10].

3. Results and Discussion

3.1. Redesign of the Void Meter Equipment

The results of the void meter redesign using SolidWorks 2019 comprise the main frame, drive mechanism, and sensor device, along with their construction details. The final design of the device consists of two units to support dynamic skid measurement on railway tracks. The device's design consists of void meter units A and B, as shown in Figure 2 below.



Void Meter Equipment Unit A

Void Meter Equipment Unit B

Figure 2. Design of Void Meter Unit A and B

DOI: https://doi.org/10.71225/jstn.v2i3.115

Description:

1. Infrared proximity sensor
2. Speed sensor bracket
3. Round iron axle
4. 0.49-inch I2C OLED LCD
5. 5V solar panel
6. Rotary encoder sensor
7. Push button
8. Coupling
9. Flange shaft coupling
10. Linear ball bearing
11. TP4056 module
12. Wemos D1 Mini – ESP8266
13. DC jack
14. Power switch
15. ESP8266 shield
16. Neodymium magnet
17. DS18B20 sensor

The results of the redesign and improvement of the third-generation void meter include the integration of a sensor system, increased power supply with solar panels, and a cloud-based data storage system to support continuous and more accurate railway track inspections. The integration of three types of rotary encoder sensors for detecting track voids and dynamic skids, a proximity infrared sensor (E18-D80NK) for measuring train speed, and a DS18B20 for monitoring track temperature results in a multi-parameter measurement system that operates simultaneously in two consolidated devices.

The new design also features a 5 Wp solar panel, combined with a 18650 3000 mAh battery and a TP4056 module, enabling the device to operate longer without external power intervention. The power system significantly enhances the mobility and operational duration of the tool in the field compared to previous generations that relied on additional power sources (power banks).

The use of the WeMos D1 Mini ESP8266 microcontroller connected to the ThingSpeak and Blynk platforms enables real-time data transmission, automatic cloud storage, and direct damage notifications to the operator's device. This system replaces the data storage method of previous-generation devices with a cloud-based system through integration with the ThingSpeak platform.

This improvement enables automatic and structured storage of measurement data, thereby supporting operational efficiency, reducing the risk of data loss, and facilitating trend analysis and regular reporting in the Internet of Things-based inspection system.

Additionally, the third-generation device is equipped with the ESP-NOW communication protocol, allowing sensor units to connect directly without relying on public Wi-Fi networks. This integration enables low-latency data transmission between devices (Unit A and Unit B) with minimal power consumption, thereby enhancing the reliability of wireless communication at the inspection site. Compared to the second-generation void meter, the significant advantages of this tool include:

a. Enhanced sensor integration and additional measurement parameters such as dynamic skilu and rail temperature,
b. Enhanced operational power supply with a 5 Wp solar panel,
c. Mechanical operational stability with improvements to the sensor mounting system and actuator,
d. Reliability of the automatic early warning notification system when skilu values exceed the 2.5 mm/m threshold, and
e. Ease of remote monitoring through Internet of Things (IoT) integration.

Overall, these redesigns and improvements represent significant advances in terms of accuracy, energy sustainability, and data digitisation, making this tool more suitable for use as a predictive inspection and maintenance system for railway infrastructure.

3.2. Field Test of Void Meter Equipment

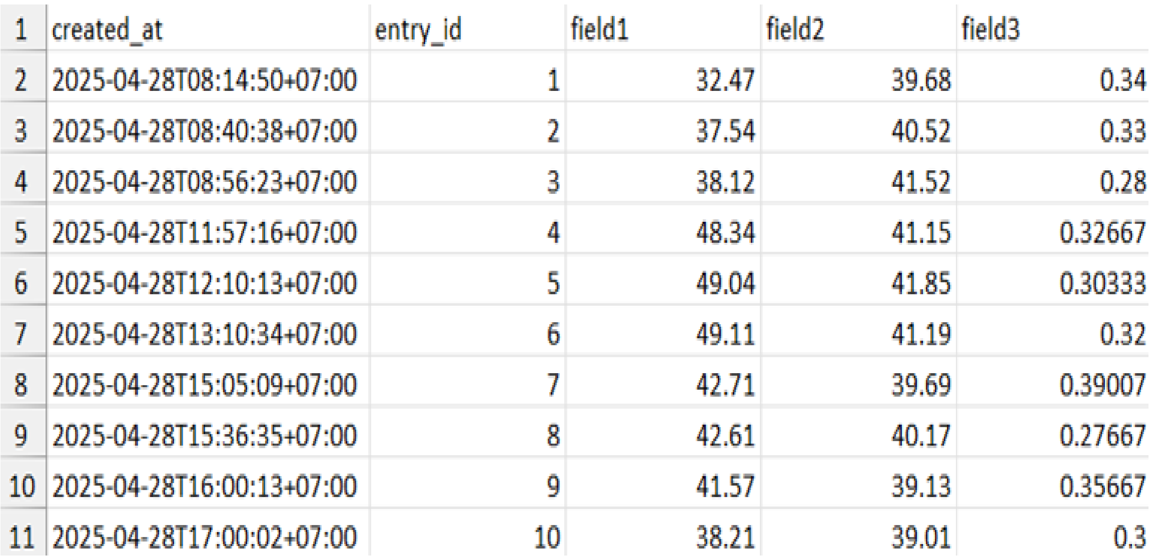
To ensure the device's performance after the development process, direct testing was conducted at the designated railway location, at kilometre 165+426 to 165+445, downstream of the Babadan–Madiun railway line. This testing aimed to assess the accuracy of ballast void measurement and dynamic skilu detection, train speed, and rail temperature under actual operational conditions. The field test results are presented visually in Figures 3 and 4, which represent the measurement output from the third-generation IoT-based void meter system.


Blynk

measurement:
notif
Hasil Melebihi Batas!

(a) (b)

Figure 3. Results of Void Meter Testing Through the Blynk and ThingSpeak Platforms (a) Platform Blynk, (b) Platform ThingSpeak



1	created_at	entry_id	field1	field2	field3
2	2025-04-28T08:14:50+07:00	1	32.47	39.68	0.34
3	2025-04-28T08:40:38+07:00	2	37.54	40.52	0.33
4	2025-04-28T08:56:23+07:00	3	38.12	41.52	0.28
5	2025-04-28T11:57:16+07:00	4	48.34	41.15	0.32667
6	2025-04-28T12:10:13+07:00	5	49.04	41.85	0.30333
7	2025-04-28T13:10:34+07:00	6	49.11	41.19	0.32
8	2025-04-28T15:05:09+07:00	7	42.71	39.69	0.39007
9	2025-04-28T15:36:35+07:00	8	42.61	40.17	0.27667
10	2025-04-28T16:00:13+07:00	9	41.57	39.13	0.35667
11	2025-04-28T17:00:02+07:00	10	38.21	39.01	0.3

Figure 4. Display of Measurement Results from the Void Meter

Based on the results of field functional testing, the third-generation void meter demonstrated optimal performance in executing all the designed measurement parameters. The system is capable

DOI: https://doi.org/10.71225/jstn.v2i3.115

of recording and displaying measurement data in real-time through integration with an Internet of Things (IoT) platform based on Blynk and ThingSpeak. Additionally, the device is equipped with an automatic notification feature that activates when measurement results exceed the predefined damage tolerance limits, thereby functioning as an Early Warning System (EWS) during railway track inspections [19].

3.3. Accuracy Test of Measurement Data from the Void Meter

Standard deviation analysis is used to evaluate the distribution of data relative to the mean value as an indicator of measurement consistency between instruments. The results of the standard deviation test for all parameters are shown in Table 1.

Table 1. Standard Deviation Test Results

Standard Deviation of Ballast Void Measurement (mm)			
Void Meter A	Densometer A	Void Meter B	Densometer B
0,492	0,504	0,495	0,509
Standard Deviation Train Speed Measurement (km/h)			
Void Meter	Stopwatch		
0,436	0,444		
Standard Deviation Rail Temperature Measurement (°C)			
Void Meter	Thermometer		
8,727	8,390		

The results of the standard deviation on the ballast void and train speed measurement data show that the standard deviation value of the void meter is lower than that of conventional instruments (densometer and stopwatch). Therefore, it can be concluded that the void meter measurement data is more centred around the average value and has better measurement consistency [6, 12]. Meanwhile, the standard deviation test results for rail temperature measurement data show that the standard deviation of the thermometer is lower than that of the void meter. Therefore, it can be concluded that the measurement data from the thermometer is more centred around the average value and has better measurement consistency.

ANOVA tests can only be performed on measurement data that has been proven to be normally distributed and homogeneous, namely on train speed and rail temperature measurement data. The results of the ANOVA test for the train speed and rail temperature parameters are shown in Tables 2 and 3.

Table 2. Results of ANOVA Test for Train Speed Measurement

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*Fcount*	*P-value*	*Ftable*
Between Groups	1,341	1,000	1,341	6,922	0,011	7,093
Within Groups	11,232	58,000	0,194			
Total	12,573	59,000				

From the calculations in the table above, we obtain Fcount > Ftable. Therefore, we can conclude that the mean (μ) of the train speed measurements between the void meter and the stopwatch is the same.

DOI: https://doi.org/10.71225/jstn.v2i3.115

Table 3. Results of ANOVA Test for Railway Track Temperature Measurement

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*count	*P-value*	*F*table
Between Groups	219,001	1,000	219,001	2,989	0,089	7,093
Within Groups	4250,114	58,000	73,278			
Total	4469,114	59,000				

From the calculations in the table above, we obtain Fcount > Ftable. Therefore, we can conclude that the mean (μ) of the train speed measurements between the void meter and the thermometer is the same. The ballast void measurement results were not normally distributed (0.318 and 0.337> 0.290). Therefore, correlation analysis of the data was conducted using the Mann–Whitney test. The results of the Mann–Whitney test for the ballast void parameter are shown in Table 4.

Table 4. Mann – Whitney Test Results for Emptiness Measurements

Test Statistics^{a}		
	Unit A Equipment Skor	Unit B Equipment Skor
Mann-Whitney U	444,000	435,000
Wilcoxon W	909,000	900,000
Z	-0,090	-0,225
Asymp. Sig. (2-tailed)	0,928	0,822

From the calculations in the table above, the result of Asymp. Sig. (2-tailed) > 0.01 was obtained. Therefore, it can be concluded that the measurement of ballast void between the void meter and densometer has the same result. The accuracy of the equipment was assessed using the Mean Absolute Percentage Error (MAPE) method. The test results are presented in Table 5.

Table 5. MAPE Test Results

Description	MAPE Value (%)	Range (%)	Conclusion
Void meter with densometer	2,440	< 10%	Highly accurate
Void meter with stopwatch	1,892	< 10%	Highly accurate
Void meter with thermometer	8,133	< 10%	Highly accurate

From the calculations in the table above, the MAPE values for ballast void, train speed, and rail temperature measurements were found to have an average MAPE value of <10%. These results demonstrate that the accuracy of the void meter measurements is comparable to that of conventional instruments (densometer, stopwatch, and thermometer).

3.4. Testing the Durability of the Void Meter in Performing Measurements

Field testing of the void meter was conducted from 07:25 to 16:59 WIB (9 hours 34 minutes) for 6 consecutive days. The test results indicate that the device can withstand normal conditions in terms of battery life, consistent with the previous discussion on battery endurance testing, which

DOI: https://doi.org/10.71225/jstn.v2i3.115

showed that the device can operate for 16 hours and 12 minutes (on a single charge and exposed to full sunlight for 6 hours).

Additionally, the test results on the consistency of data measurements over 1 day and even 6 consecutive days, proved that the void meter device can maintain measurement consistency and accuracy without any decline. This is evidenced by the data analysis results from the previous discussion, which show that the void meter device has accurate and consistent measurement performance compared to conventional devices (densometer, stopwatch, thermometer), and the MAPE value < 10% across all parameters indicates the device's very high accuracy level.

3.5. Analysis of the Implementation and Utilisation of Early Warning Systems (EWS)

The implementation of an early warning system (EWS) on the third-generation void meter is a crucial improvement in the design of the device, aimed at quickly and in real-time detecting railway track damage, particularly damage caused by dynamic deflection exceeding the tolerance threshold of 2.5 mm/m, as per PD No. 10 KAI 2016. Technically, this system is integrated through the Blynk platform as a notification system and ThingSpeak as a cloud-based data storage and presentation system. The WeMos D1 Mini ESP8266 microcontroller serves as the main controller, transmitting measurement results to both platforms. When measurement values exceed the threshold, the system automatically sends notifications to the operator's device via the Blynk app. The system enables faster decision-making without waiting for manual processing of measurement results.

The use of the early warning system has proven effective in detecting damage, thereby accelerating on-site mitigation processes. This system supports the principle of predictive maintenance, where potential damage can be identified before causing a train derailment on the railway tracks. Additionally, data storage on the ThingSpeak platform includes historical documentation of measurement results and data downloads in Excel format, which is highly useful for analysing damage trends and periodic reporting. Overall, the implementation of the early warning system (EWS) on the third-generation void meter demonstrates a significant contribution to digital transformation in the field of railway track inspection, by adding automation functions, real-time notifications, and IoT-based data integration to support a more adaptive and responsive monitoring system.

3.6. Cost and Benefit Analysis

The prices of comparable components in the field, as indicated by existing manual measuring instruments based on KNKT procurement data for the 2018 fiscal year, are as follows.

Table 6. Calculation of Existing Equipment Prices (Densometer)

No.	Component	Unit Price	Total Price
1.	Densometer	2 x 2.734.800	5.469.600

Table 6 shows the price data for the procurement of existing measuring instruments. Based on the total price of the void meter and densometer, the comparison of material values between the two is as follows:

DOI: https://doi.org/10.71225/jstn.v2i3.115

$$Economic\ Effectiveness$$

$$= \left|\frac{\text{void meter equipment cost}-densometer\text{ tool cost}}{densometer\text{ tool cost}}\right| \times 100\% \tag{1}$$

$$= \left|\frac{2.204.150-5.469.600}{5.469.600}\right| \times 100\% \tag{2}$$

$$= \mathbf{59,701}\% \tag{3}$$

The results of the calculation show that the void meter is 59.70% more cost-effective than the densometer. This saving is very significant, especially in the context of procuring large quantities of measuring instruments for field operations.

Technically, this cost reduction is achieved without compromising the main functions of the device, which are to detect voids under bearings and dynamic skilu. Furthermore, with the support of Internet of Things (IoT) technology, the void meter can transmit real-time data to cloud platforms such as Blynk and ThingSpeak. This advantage not only impacts cost efficiency but also enhances the effectiveness and speed of decision-making on-site. As a result, operators or regulators can implement a void meter inspection system on a larger scale without being burdened by material costs.

4. Conclusion

The third-generation Internet of Things-based void meter demonstrates superior performance in measuring void response accuracy, dynamic skilu, train speed, and rail temperature. Through functional testing and statistical analysis such as standard deviation tests, ANOVA, Mann–Whitney, and MAPE, evidence was obtained that the device has a high level of consistency and accuracy, with a MAPE value < 10% for all parameters. The integration of coordinated sensor systems, ESP-NOW communication between device units, and real-time notification systems based on Blynk and ThingSpeak cloud storage enables adaptive monitoring capabilities and early warnings of infrastructure damage, aligning with the principles of predictive maintenance in railway track inspections. From an economic perspective, the device is designed with a total production cost of Rp 2,204,150.00, which is significantly more efficient than conventional inspection devices, such as digital densometers. With low costs and advanced features like remote monitoring, cloud-based historical data, and self-sufficient power through solar panels, the device offers a high cost-benefit ratio. Therefore, the third-generation void meter is a worthy alternative technological solution that is efficient, reliable, and economical, supporting the digital transformation of railway infrastructure inspection systems in Indonesia. To improve the accuracy of measurement data in the next generation of void-meter, further development of signal processing algorithms and sensor calibration is recommended to minimise deviations that may occur in various environmental conditions. The use of sensors with higher sensitivity, combined with the addition of dynamic modelling-based temperature compensation features, can enhance the consistency of measurement results across a range of weather conditions and traffic loads. In addition, integrating machine learning-based data processing methods could be a potential strategy for clustering patterns of irregularity in skilu values and detecting damage earlier. Further testing is also needed across a wider range of temperatures and speeds to ensure the system's robustness in a continuous, real-time operational context.

Acknowledgements

The author would like to express sincere gratitude and appreciation to the supervising lecturer for their guidance, corrections, and significant scientific contributions during the preparation and implementation of this research. The author would also like to thank the Railway Operation Regional (DAOP 7) Madiun, especially the railway Maintenance Team, for granting access to the site and providing full support during the primary data collection process, including the provision of testing infrastructure and technical supervision in the field. The contributions from both parties were crucial in ensuring the integrity of the data and the validity of the test results under actual operational conditions.

References

[1] X. Liu, M. R. Saat, and C. P. L. Barkan, "Analysis of causes of major train derailment and their effect on accident rates," *Transp. Res. Rec.*, no. 2289, pp. 154–163, 2012, doi: 10.3141/2289-20.

[2] Laporan Tahunan Komite Nasional Keselamatan Transportasi (KNKT) Tahun 2020, "Laporan Tahunan 2021," pp. 220–225, 2021.

[3] A. Friscilya and A. F. Ismaili, "Analysis Of Damage and Track Quality Index (TQI) On Rail Road Components (Case Study: Cross Wates Station-Sentolo Station Km.516+300-Km.520+300 Operational Area 6 Yogyakarta)," pp. 1–2, 2021.

[4] M. Sysyn, O. Nabochenko, and V. Kovalchuk, "Experimental investigation of the dynamic behavior of railway track with sleeper voids," *Railw. Eng. Sci.*, vol. 28, no. 3, pp. 290–304, 2020, doi: 10.1007/s40534-020-00217-8.

[5] S. Kaewunruen, J. Sresakoolchai, and H. Stittle, *Machine Learning to Identify Dynamic Properties of Railway Track Components*, vol. 22, no. 11. 2022. doi: 10.1142/S0219455422501097.

[6] B. Leitner, "A General Model for Railway Systems Risk Assessment with the Use of Railway Accident Scenarios Analysis," *Procedia Eng.*, vol. 187, pp. 150–159, 2017, doi: 10.1016/j.proeng.2017.04.361.

[7] A. De Rosa *et al.*, "Monitoring of lateral and cross level track geometry irregularities through onboard vehicle dynamics measurements using machine learning classification algorithms," *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit*, vol. 235, no. 1, pp. 107–120, 2021, doi: 10.1177/0954409720906649.

[8] B. Environment and W. I. T. Press, "Transactions on the Built Environment vol 11, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509," vol. 11, 1995.

[9] K. Marciniak, P. Majewski, and J. Reiner, "Inspection of railway catenary systems using machine learning with domain knowledge integration," *Sci. Rep.*, vol. 15, no. 1, pp. 1–17, 2025, doi: 10.1038/s41598-025-15289-x.

[10] D. Sanjaya Atmaja, P. Mahendra Shakti, and M. Willy Eka Pratama, "Perencanaan dan Pembuatan Alat Pendeteksi Skilu Dinamis pada jalan rel kereta api," *J. Perkeretaapi. Indones.*, vol. I, no. November, pp. 75–79, 2017.

[11] N. Kaviani, P. S. Ricci, P. R. Licciardello, and P. L. Rizzetto, *Track Geometry Monitoring using Measured Data from*. 2024.

[12] B. B. Y. Afriansyah, "Re-Desain Alat Void Meter Berbasis Mikrokontroler Untuk Pemeriksaan Jalan Rel," 2024.

[13] B. R. Nugroho, W. T. Adi, and H. W. Puruhita, "RE – DESAIN DAN PENINGKATAN ALAT PEMERIKSAAN JALAN REL ' VOID METER ' BERBASIS INTERNET OF THINGS," vol. x, no. x, pp. 1–10, 2025.

[14] S. Pitou, "A Guide for Students," *Renascence*, vol. 13, no. 1, pp. 52–53, 1960, doi: 10.5840/renascence196013115.

[15] O. Jurjut, P. Georgieva, L. Busse, and S. Katzner, "Learning enhances sensory processing in

mouse V1 before improving behavior," *J. Neurosci.*, vol. 37, no. 27, pp. 6460–6474, 2017, doi: 10.1523/JNEUROSCI.3485-16.2017.

[16] B. S. Qolby, "Uji mann whitney dalam statistika non parametrik perbedaan tingkat penggunaan kendaraan umum dengan kendaraan pribadi," *J. PkM Pengabdi. Kpd. Masy.*, vol. 2, no. 8, p. 15, 2014.

[17] C. Kasemset, N. Sae-Haew, and A. Sopadang, "Multiple regression model for forecasting quantity of supply of off-season longan," *Chiang Mai Univ. J. Nat. Sci.*, vol. 13, no. 3, pp. 391–402, 2014, doi: 10.12982/cmujns.2014.0044.

[18] I. Nurvianti, B. D. Setiawan, and F. A. Bachtiar, "Peramalan Jumlah Penumpang Keberangkatan Kereta Api di DKI Jakarta Menggunakan Metode Double Exponential Smoothing dan Triple Exponential Smoothing," *Pengemb. Teknol. Inf. dan Ilmu Komput.*, vol. 3, no. 6, pp. 5257–5263, 2019, [Online]. Available: http://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/5458%0Ahttp://j-ptiik.ub.ac.id/index.php/j-ptiik/article/download/5458/2567

[19] D. Abas, A. Ghany, T. Shekhan, and U. P. Duhok, "Perancangan Sistem Pemantauan EKG Berbasis Kesehatan Aplikasi Blynk untuk Internet of Things Machine," vol. 01, no. 02, pp. 106–111, 2020.

[20] Wijayanti and Dewi Nurhidayati, "Perbandingan Alat Ukur dalam Penentuan Ketebalan Kulit Imitasi," *Berk. Penelit. Teknol. Kulit, Sepatu, dan Prod. Kulit*, vol. 21, no. 1, pp. 18–23, 2022, doi: 10.58533/bptkspk.v21i1.156.