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Analysis of Road Pavement Conditions Using the Surface Distress Index (SDI) and International Roughness Index (IRI) Methods Based on the RoadLab Application on the Gunungwungkal–Sumberrejo Road Section, Pati, STA 0+000–3+000

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Abstract

Good pavement conditions are essential for supporting safe and efficient transportation activities on the road. The Gunungwungkal–Sumberrejo road in Pati Regency has experienced various types of pavement distress that may reduce road serviceability and driving comfort. This study aims to evaluate pavement conditions using the Surface Distress Index (SDI) and International Roughness Index (IRI) methods, assess the relationship between the two indicators, and determine appropriate maintenance treatments. The study was conducted along the Gunungwungkal–Sumberrejo road from STA 0+000 to STA 3+000, divided into 30 segments of 100 m each. SDI data were obtained through visual field observations, while IRI data were measured using the RoadLab application. The results showed an average SDI value of 200.83, classified as heavily damaged, although 67% of segments were categorized as good. The average IRI value was 6.1523 m/km, with 47% of segments classified as fair and no segments classified as heavily damaged. The correlation coefficient between SDI and IRI was 0.355, indicating a weak positive relationship. The integrated assessment resulted in a good pavement condition, with recommended treatments consisting of 20% routine maintenance, 37% periodic maintenance, 20% rehabilitation, and 23% reconstruction. The findings also indicate that pavement deterioration was distributed unevenly along the road section, emphasizing the importance of segment-level evaluation in determining maintenance priorities. Therefore, the combination of SDI and IRI can support more targeted and effective pavement management decisions.

Keywords: *IRI, Pavement Condition, Road Maintenance, RoadLab, SDI.*

INTRODUCTION

Road infrastructure constitutes a critical component of contemporary transportation systems because its performance directly influences population mobility, the distribution of goods and services, regional accessibility, and the efficiency of economic activities. As transport demand continues to expand, the quality of road infrastructure increasingly determines the reliability, safety, and cost-effectiveness of movement between residential, commercial, and productive areas. The management of road infrastructure therefore requires an integrated understanding of pavement performance, traffic characteristics, structural capacity, and surface condition rather than relying solely on periodic physical maintenance. Recent developments in pavement engineering have increasingly emphasized systematic condition assessment as a basis for prioritizing maintenance and rehabilitation interventions, particularly where road networks must be managed under constrained resources (Direktorat Jenderal Bina Marga, 2021). The increasing complexity of transportation networks also strengthens the need for condition assessment approaches capable of generating objective and spatially representative information for decision-making. Pavement deterioration is influenced by interacting traffic, environmental, drainage, material, and construction factors, making continuous monitoring essential for identifying deterioration patterns before they develop into more extensive pavement failures (Novitasari & Iskandar, 2017). In this context, intelligent and technology-supported pavement assessment has emerged as an important direction for improving the efficiency, consistency, and scalability of road condition monitoring.

The deterioration of pavement surfaces represents a persistent engineering problem because repeated axle loading, environmental exposure, drainage deficiencies, construction quality, and inadequate maintenance progressively alter both the structural and functional characteristics of road surfaces. Previous research has demonstrated that road deterioration can manifest through interconnected forms of distress, including cracking, potholes, rutting, surface deformation, and roughness, each of which can affect vehicle safety, riding comfort, and operating costs (Desei et al., 2023). Traffic characteristics are particularly important because variations in traffic volume and loading intensity can accelerate pavement deterioration and produce differences in measured pavement condition across road segments (Mulyana et al., 2025). The engineering response to such deterioration requires assessment procedures that can distinguish the severity and functional implications of pavement defects rather than merely documenting their visual presence. Conventional pavement evaluation approaches have provided valuable frameworks for maintenance decisions, yet differences in assessment principles can generate different interpretations of pavement condition when visual distress and surface roughness are evaluated independently (Mubarak, 2016). This issue has encouraged researchers to combine complementary indicators, particularly the Surface Distress Index (SDI), which captures visible surface deterioration, and the International Roughness Index (IRI), which represents longitudinal pavement roughness and its implications for riding quality (Maulana et al., 2023). The combination of these indicators provides a broader functional representation of pavement performance because a road may exhibit limited visible distress while still producing substantial roughness, or conversely display visible defects without an equivalent level of longitudinal unevenness.

Recent empirical studies have strengthened the relevance of SDI and IRI as complementary indicators for pavement condition assessment, yet their application also reveals methodological differences that remain insufficiently resolved. Comparative analysis using Roadroid has shown that SDI and IRI can generate distinct condition profiles because the two indicators capture different dimensions of pavement performance and respond differently to observed surface characteristics (Utama et al., 2023). Research incorporating traffic characteristics further indicates that pavement condition cannot be interpreted independently from the operational loading environment, suggesting that numerical condition indices should be contextualized within the characteristics of the road being evaluated (Mulyana et al., 2025). At the same time, the application of mobile-based technologies has introduced opportunities to reduce the dependence on labor-intensive conventional surveys while increasing the speed of field data acquisition. RoadLab Pro has been applied to integrate road roughness assessment with pavement condition indicators, demonstrating the potential of smartphone-based monitoring for practical road evaluation (Widianto et al., 2022). These developments indicate a shift from exclusively manual inspection toward data acquisition supported by embedded smartphone sensors and application-based processing. Nevertheless, differences in road characteristics, survey procedures, device configuration, traffic conditions, and interpretation criteria may affect the comparability of results between locations. The methodological challenge is therefore not merely whether mobile applications can measure pavement condition, but whether their outputs can provide sufficiently coherent evidence when SDI and IRI are jointly used to characterize a specific road segment.

A further limitation in the existing literature concerns the relatively strong emphasis on demonstrating the feasibility of individual assessment methods, while fewer studies critically examine how SDI and IRI derived from mobile-based applications can be jointly interpreted for localized maintenance decision-making. Although smartphone-based Roadroid assessment has been shown to provide practical pavement-condition information, its effectiveness remains dependent on the relationship between sensor-derived roughness measurements and independently observed surface distress (Ahmad & Kushari, 2025). The use of RoadLab-based measurements similarly offers efficiency advantages, but the resulting data still require contextual interpretation because numerical roughness values alone cannot fully represent the type, distribution, or severity of visible pavement distress. Earlier technical guidance has established systematic procedures for road-condition surveys and maintenance assessment, yet the increasing availability of digital measurement technologies creates a need to examine how these established principles can be operationalized through contemporary mobile applications (Direktorat Jenderal Bina Marga, 2011). The gap becomes more significant for regional road sections where detailed pavement monitoring may be constrained by limited personnel, equipment, time, and financial resources. A road-condition assessment that is rapid but insufficiently representative may produce inappropriate maintenance priorities, whereas a highly detailed conventional survey may be impractical for repeated monitoring across extensive road networks. This tension between assessment accuracy, operational efficiency, and field practicality constitutes an important empirical problem for intelligent pavement-management research.

The urgency of addressing this problem is particularly evident on regional road sections that function as important connectors but may not receive the same level of monitoring intensity as major arterial or urban corridors. Effective pavement evaluation is required not only to identify existing defects but also to support evidence-based decisions concerning routine maintenance, periodic maintenance, rehabilitation, and the prioritization of road segments requiring intervention. Indonesian road-management guidance emphasizes the importance of systematic maintenance practices to preserve road serviceability and prevent deterioration from progressing into conditions requiring more extensive and costly treatment (Badan Pusat Pengembangan dan Penelitian Prasarana Transportasi, 2005). Recent studies on alternative road-treatment selection likewise demonstrate that pavement-condition information is fundamental for matching the observed level of deterioration with an appropriate intervention strategy (Putra et al., 2023). The Gunungwungkal–Sumberrejo road section in Pati represents a relevant empirical setting because localized pavement conditions need to be identified through a method that is both sufficiently informative and operationally efficient for a three-kilometre assessment corridor. The use of RoadLab provides an opportunity to obtain IRI-related measurements through smartphone-based sensing while SDI assessment can document the visible manifestations of pavement deterioration. Examining the two indicators together can reveal whether the functional roughness of the road corresponds with its observed surface distress and can provide a more comprehensive basis for interpreting pavement serviceability. Such an assessment is practically important because reliable condition information can support more rational maintenance prioritization while reducing dependence on resource-intensive field-survey procedures.

Within this research landscape, the present study is positioned at the intersection of pavement condition assessment, mobile sensing technology, and data-informed road maintenance decision-making. Rather than treating SDI and IRI as isolated numerical outputs, the study integrates both indicators to characterize the functional and visible condition of the Gunungwungkal–Sumberrejo road section, Pati, from STA 0+000 to STA 3+000. The approach responds to the growing demand for efficient road-monitoring systems capable of transforming field observations and sensor-based measurements into actionable pavement-condition information. The methodological relevance is supported by recent evidence that RoadLab and comparable smartphone-based applications can facilitate practical pavement surveys while reducing the operational burden associated with conventional assessment techniques (Fauji & Kushari, 2025). The study also extends the application of mobile-based pavement assessment by focusing on a defined regional road corridor and examining the relationship between surface distress and longitudinal roughness at the segment level. This positioning enables the research to address an empirical gap concerning how SDI and IRI measurements obtained within a localized road corridor can jointly support a more nuanced interpretation of pavement condition. The research therefore contributes not simply another numerical evaluation of road damage, but an integrated assessment framework that connects visible pavement distress, measured roughness, and the practical requirements of road-condition monitoring. The study aims to analyze the pavement condition of the Gunungwungkal–Sumberrejo road section at STA 0+000–3+000 using the SDI and IRI methods based on the RoadLab application, with the objective of identifying the condition level of each road segment and formulating an evidence-based interpretation of pavement performance. The principal contribution lies in demonstrating a methodological approach for integrating smartphone-based roughness measurement with systematic surface-distress assessment, thereby providing a practical and replicable basis for intelligent pavement-condition evaluation and maintenance prioritization.

RESEARCH METHODS

This study employed an empirical quantitative-descriptive design involving direct field measurements of pavement surface distress and roughness on the Gunungwungkal–Sumberrejo Road, Pati, from STA 0+000 to STA 3+000, with the 3,000 m road section divided into 30 observation segments of 100 m each and an effective pavement width of approximately 6 m. The research architecture consisted of two integrated measurement streams, namely visual pavement-distress assessment for the Surface Distress Index (SDI) and smartphone-based roughness measurement for the

International Roughness Index (IRI), followed by segment-level data processing and integrated pavement-condition classification. Primary field data were collected during 1–20 May 2026 through direct observation and measurement of pavement defects, following the principle of systematic road-condition surveying established by the Directorate General of Highways (Direktorat Jenderal Bina Marga, 2011). The SDI survey was conducted by walking along each 100 m segment and recording the percentage of cracked area, crack width, number of potholes, and rut depth, which were subsequently converted into hierarchical SDI components consisting of SDI1, SDI2, SDI3, and SDI4. The IRI survey used the RoadLab application installed on a smartphone positioned vertically on the dashboard of a survey vehicle with soft suspension, while the vehicle was operated at a relatively constant speed of 20–40 km/h to capture vehicle vibration through the smartphone accelerometer and positioning information through GPS. Each carriageway was surveyed through two runs on the left lane and two runs on the right lane to reduce the influence of individual vehicle passes and provide repeated observations for segment-level roughness estimation, following the practical application of smartphone-based road-condition assessment reported in previous research (Widianto et al., 2022). The resulting SDI observations and RoadLab IRI records constituted the primary empirical dataset used to characterize pavement condition and establish the subsequent analytical relationship between visible distress and surface roughness.

The testing procedure began with independent processing of SDI and IRI data for each 100 m segment before the two indicators were integrated into the final pavement-condition assessment. SDI values were calculated sequentially from the measured distress parameters by applying the prescribed weighting and accumulation procedure, with the resulting values classified as Good (<50), Fair (50–100), Lightly Damaged (100–150), or Heavily Damaged (>150), consistent with the SDI-based pavement evaluation approach used in previous road-condition studies (Desei et al., 2023). RoadLab measurement files were exported in CSV format and processed using Microsoft Excel to obtain the mean estimated IRI (eIRI) for each observation segment, after which the resulting values were classified according to the applicable Bina Marga pavement-condition criteria. Repeated IRI passes served as an internal consistency check, while the comparison between SDI and IRI provided a cross-parameter validation mechanism for determining whether visually observed deterioration was accompanied by corresponding increases in longitudinal roughness. The relationship between pavement distress and roughness was evaluated using the Pearson correlation coefficient, with SDI treated as the independent variable and IRI as the dependent variable. The use of SDI and IRI as complementary indicators was selected because previous comparative research has shown that the two parameters capture different but interconnected dimensions of pavement performance and can therefore provide a broader representation when interpreted jointly (Utama et al., 2023). Finally, the validated segment-level results were entered into a pavement-condition matrix based on Bina Marga provisions to determine the appropriate maintenance response, including routine maintenance, periodic maintenance, rehabilitation, or reconstruction. The integrated SDI–IRI assessment was subsequently used as the principal performance evaluation to identify deterioration severity, characterize pavement condition at each segment, and establish maintenance priorities for the Gunungwungkal–Sumberrejo road section.

RESULTS AND DISCUSSION

Pavement Distress Characteristics and Field Observation Results

Field observations were conducted on the Gunungwungkal–Sumberrejo road section in Pati, covering STA 0+000–3+000, to identify the type, distribution, and characteristics of pavement distress. The observation was divided into 30 segments, with each segment representing a 100 m road section. The identified pavement distresses included depression, cracking, potholes, patching, and wheel tracks. The field data showed that pavement conditions varied considerably among the segments, with some sections experiencing relatively minor surface deterioration and others exhibiting more pronounced distress. This variation indicates that pavement deterioration along the study section was spatially non-uniform. The field observations subsequently served as the primary basis for calculating the Surface Distress Index (SDI) for each segment.

The observations in Segments 1–6 showed a combination of localized surface defects and early signs of pavement deterioration. Segment 1 contained an existing patch, while Segments 2 and 4 showed moderate raveling caused by the loss of asphalt binder from the pavement surface. Segment 3 recorded 14 light potholes, representing the most prominent localized surface defect within this initial group of segments. Fine cracks were also observed on the patch in Segment 5, while Segment 6 exhibited fatigue-related cracking. These conditions indicate that several forms of distress had already developed during the initial 600 m of the observed road section. The presence of patching followed by cracking also suggests that previously repaired areas remained susceptible to subsequent deterioration.

Segments 7–12 showed a further variation in pavement distress, particularly in the form of potholes, patching, depression, and raveling. Segment 7 was characterized by patching accompanied by raveling and localized depression, while Segment 8 contained small potholes requiring attention. Moderate depression was identified in Segments 9, 10, and 12, accompanied by uneven surfaces, surface wear, and initial cracking patterns. Segment 11 represented one of the more critical locations in this interval because heavy raveling occurred together with alligator cracking. The combination of these defects indicates a more advanced deterioration condition compared with isolated surface defects. The distribution of distress in this interval also demonstrates that different mechanisms of pavement deterioration could occur within relatively short distances along the same road section.

The middle portion of the road, particularly Segments 13–18, was characterized mainly by structural cracking and surface deformation. Longitudinal cracking and light-to-moderate alligator cracking were observed in Segments 13, 14, 15, and 18, indicating the influence of repeated vehicle loading on the pavement surface. Segment 16 exhibited a more severe condition, with moderate-to-heavy alligator cracking accompanied by raveling and old patching along the wheel path. Segment 17 showed pavement depression that could reduce the service quality of the road. In Segment 18, longitudinal cracking had progressed toward material loss and the initial formation of new potholes. This progression demonstrates that cracking and surface deformation may develop together and gradually increase the severity of pavement deterioration.

In Segments 19–24, the observed distress varied from functional deterioration to material loss at the pavement surface. Segment 19 contained potholes caused by the loss of surface-layer material, creating a potential safety concern for road users. Moderate depression was identified in Segments 20, 23, and 24, characterized by concave areas, uneven surfaces, and surface weathering. Segments 21 and 22 exhibited comparatively lighter conditions, consisting of small longitudinal cracks and light raveling associated with the loss of asphalt binder. The observations therefore show that pavement deterioration did not consistently increase with increasing STA, but instead fluctuated between segments. Such fluctuations emphasize the importance of evaluating pavement conditions at the segment level rather than relying only on an overall description of the road section.

The final observation interval, comprising Segments 25–30, was dominated by pavement depression and aggregate loss. Segments 25, 26, 27, and 30 showed moderate depression and uneven pavement surfaces that could accelerate further deterioration when exposed to water accumulation. Meanwhile, Segments 28 and 29 experienced light-to-moderate raveling associated with reduced asphalt bonding. Overall, the field survey confirmed that the Gunungwungkal–Sumberrejo road section contained several forms of pavement distress with different levels of severity and distribution. Although existing patches were still functioning in several segments to cover previous damage, localized repairs and periodic maintenance were considered necessary to prevent further deterioration. These field findings provide the fundamental input for the subsequent SDI assessment because the observed dimensions, quantities, and types of distress are used to characterize pavement condition quantitatively.

Table 1. Road Distress Data of Gunungwungkal–Sumberrejo Road, Pati, Segments 1–30

Segment	Sta	Depression P (M)	L (M)	T (M)	Cracking P (M)	L (M)	T (M)	Potholes	Patching P (M)	L (M)	H (M)	Wheel Tracks
1	0+000–0+100	-	-	-	0.35	0.10	0.02	-	6	1.5	-	-
2	0+100–0+200	-	-	-	0.60	0.08	0.01	2	2	1	0.03	1.7; 1.5; 0.03
3	0+200–0+300	2	0.70	0.05	0.5	0.70	0.01	14	0.7	0.4	0.03	-
4	0+300–0+400	-	-	-	1.3	0.40	0.025	12	-	-	-	-
5	0+400–0+500	1.5	1	0.018	-	-	-	4	0.42	0.50	-	0.47; 0.70
6	0+500–0+600	-	-	-	0.30	0.20	0.03	3	0.50	0.40	-	-
7	0+600–0+700	-	-	-	-	-	-	20	-	-	-	-
8	0+700–0+800	-	-	-	0.55	0.75	0.03	16	1	0.7	0.40	0.60
9	0+800–0+900	3	0.50	0.03	-	-	-	-	1	0.70	0.07	-
10	0+900–1+000	2	1.00	0.05	-	-	-	3	-	-	-	-
11	1+000–1+100	-	-	-	0.03	0.02	0.05	-	-	-	-	-
12	1+100–1+200	-	-	-	0.7	0.50	0.08	-	3	0.50	0.10	-
13	1+200–1+300	-	-	-	-	-	-	-	2	0.15	0.05	-
14	1+300–1+400	-	-	-	1.5	0.10	0.08	-	-	-	-	-
15	1+400–1+500	-	-	-	0.70	0.20	0.05	-	-	-	-	-
16	1+500–1+600	3	0.50	0.05	2	0.30	0.06	-	-	-	-	-
17	1+600–1+700	5	0.50	0.03	-	-	-	-	-	-	-	-
18	1+700–1+800	2.5	0.80	0.03	0.70	0.40	0.03	1	4	1.00	0.05	-
19	1+800–1+900	-	-	-	4	0.70	0.03	1	-	-	-	-
20	1+900–2+000	3	1	0.08	0.80	0.30	0.02	-	3	1.5	0.05	-
21	2+000–2+100	5	1.5	0.09	3	0.05	0.015	1	-	-	-	-
22	2+100–2+200	3	1	0.02	-	-	-	-	5	1.6	0.038	-
23	2+200–2+300	6	1.3	0.032	-	-	-	-	-	-	-	-
24	2+300–2+400	2	0.80	0.041	-	-	-	-	1.5	0.60	0.035	-
25	2+400–2+500	4	1	0.016	-	-	-	-	3	1.2	0.018	-
26	2+500–2+600	2	0.80	0.02	-	-	-	-	-	-	-	-
27	2+600–2+700	3	0.50	0.025	-	-	-	-	-	-	-	-
28	2+700–2+800	2	0.30	0.03	-	-	-	-	-	-	-	-
29	2+800–2+900	-	-	-	0.55	0.05	0.01	-	-	-	-	-
30	2+900–3+000	-	-	-	-	-	-	2	0.45	0.40	-	-

Surface Distress Index (SDI) Assessment and Pavement Condition

The visual pavement-condition data were subsequently processed using the Surface Distress Index (SDI) to quantify the level of surface deterioration in each 100 m segment. SDI is determined from several visible pavement-distress parameters, including crack area, crack width, number of potholes, and wheel-rut depth, so that the visual observations can be converted into a standardized pavement-condition indicator. The calculation was performed for Segments 1–30 using the field measurements presented in the previous section. The initial calculation used the percentage of pavement area affected by cracking as the first SDI component, followed by crack width, pothole quantity, and wheel-rut depth. For example, the calculation for Segment 3 produced a crack-area percentage of 5.83%, which was categorized as less than 10% and therefore generated an SDI1 value of 5. The resulting values from each distress parameter were then accumulated progressively to obtain the final SDI value for each segment.

The calculation for Segment 3 illustrates how the individual distress parameters influenced the final pavement-condition index. The measured crack area was 5.83%, resulting in an SDI1 value of 5, while the measured crack width of 5.0 mm produced an SDI2 value of 10. The segment contained 14 potholes, which resulted in a substantial increase in the index and produced an SDI3 value of 235. A wheel-rut depth of 3.0 cm further increased the value to SDI4 = 245. The final SDI value of 245 placed Segment 3 in the heavily damaged category. This example demonstrates that the number of potholes and wheel-rut depth can substantially influence the final SDI when several distress parameters occur simultaneously.

The calculated SDI values varied considerably among the 30 segments, reflecting the heterogeneous pavement conditions identified during the visual survey. Segments 1, 9, 11, 13–19, and 21–29 generally produced low SDI values and were classified as good, although some of these segments still contained measurable cracking, potholes, or other surface defects. In contrast, Segments 2, 3, 4, 7, and 8 recorded substantially higher SDI values and were categorized as heavily damaged. Segment 8 recorded the highest value in the presented analysis, with an SDI of 335, followed by Segment 3 with an SDI of 245 and Segments 4 and 7 with values of 235 and 225, respectively. Several other segments, including Segments 5, 6, 10, 12, and 30, were classified as having moderate conditions based on their respective SDI values. These differences confirm that the severity of pavement distress was concentrated in particular locations rather than being evenly distributed across the entire road section.

Table 2. Recapitulation of SDI Data of Gunungwungkal–Sumberrejo Road, Pati, Segments 1–30

Segment	Pavement Surface				Cracking			Other Distress		
	Composition	Condition	Subsidence	Patch	Type	Width	Area	Hole	Sizs	Wheel Tracks
1	2	3	1	2	2	3	3	1	4	1
2	2	3	1	2	4	3	4	3	2	3
3	2	3	1	2	3	3	3	4	4	3
4	2	3	1	1	3	3	3	4	5	1
5	2	3	2	2	1	1	1	3	3	1
6	1	3	1	2	2	3	3	3	4	1
7	2	3	1	1	1	1	1	4	5	1
8	2	3	1	2	2	3	3	4	4	2
9	2	3	2	1	1	1	1	1	1	1
10	2	3	2	1	1	1	1	3	3	1
11	2	3	1	1	4	3	3	1	1	1
12	2	3	1	1	3	3	4	1	1	1
13	2	3	1	1	3	3	3	1	1	1
14	2	3	1	1	3	3	3	1	1	1
15	2	3	1	1	4	3	3	1	1	1
16	2	3	2	1	2	3	3	1	1	1
17	2	3	2	1	1	1	1	1	1	1
18	2	3	2	1	3	3	3	2	4	1
19	2	3	1	1	3	3	3	2	2	1
20	2	3	2	1	3	3	3	1	1	1
21	2	3	2	1	4	3	3	2	4	1
22	2	3	2	1	1	1	1	1	1	1
23	2	3	2	1	1	1	1	1	1	1
24	2	3	2	1	1	1	1	1	1	1
25	2	3	2	1	1	1	1	1	1	1
26	2	3	2	1	1	1	1	2	1	1
27	2	3	2	1	1	1	1	1	1	1
28	1	1	2	1	1	1	1	2	1	1
29	1	1	1	1	2	2	3	1	1	1
30	1	1	1	2	1	1	1	3	2	1

The overall SDI assessment indicates that the average pavement-condition value was 200.83, which was classified in the heavily damaged category according to the condition classification used in the study. Higher SDI values indicate more severe surface deterioration, while lower values indicate better pavement conditions. The average value is strongly influenced by several segments with high SDI values, particularly Segments 2, 3, 4, 7, and 8. Nevertheless, the segment-level results show that a considerable proportion of the road still had good surface conditions despite the high overall average. This distinction is important because the average SDI alone does not fully describe the spatial distribution of pavement distress along the 3,000 m road section. The findings therefore demonstrate the usefulness of combining the overall index with segment-level classification when determining pavement maintenance priorities.

Table 3. SDI Data Analysis Results

Segment	Crack Area (%)	Crack Width (mm)	Number of Potholes	Wheel-Rut Depth (cm)	SDI Value	Condition
1	0.58	4.0	0	0	10	Good
2	43.5	40	4	3	165	Heavily Damaged
3	5.83	5	14	3	245	Heavily Damaged
4	8.6	5	4	0	235	Heavily Damaged
5	0	0	0	0	75	Fair
6	1.00	3.0	0	0	85	Fair
7	0	0	0	0	225	Heavily Damaged

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8	6.97	5	4	4	335	Heavily Damaged
9	0	0	0	0	0	Good
10	0	0	0	0	75	Fair
11	0.01	5.0	0	0	10	Good
12	30.8	3	0	0	80	Fair
13	6	5	0	0	10	Good
14	2.5	5	0	0	10	Good
15	2.3	5	0	0	10	Good
16	10	5	0	0	5	Good
17	0	0	0	0	0	Good
18	4.6	5	0	0	25	Good
19	4.6	5	0	0	25	Good
20	21.9	20	0	0	40	Good
21	0	0	0	0	15	Good
22	0	0	0	0	0	Good
23	50	40	0	0	40	Good
24	0	0	0	0	0	Good
25	0	0	0	0	0	Good
26	0	0	0	0	15	Good
27	0	0	0	0	0	Good
28	0	0	0	0	15	Good
29	0.45	8	5	0.05	5	Good
30	0	0	0	0	75	Fair

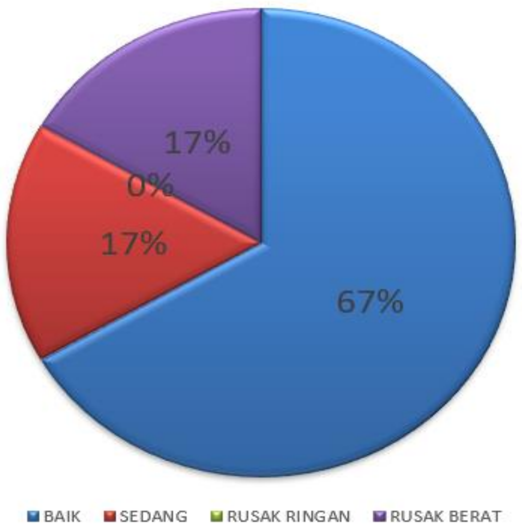

Figure 1. Recapitulation of SDI Condition Percentage

The distribution of pavement conditions provides a more detailed interpretation of the segment-level SDI results. Based on the original analysis, 67% of the observed segments were categorized as good, 17% as fair, 0% as lightly damaged, and 17% as heavily damaged. The distribution indicates that although the calculated average SDI falls within the heavily damaged category, most individual segments were classified as good. This apparent difference results from the presence of several segments with very high SDI values that substantially increase the overall average. The condition distribution therefore highlights the importance of examining both central tendency and segment-level classification when interpreting pavement performance. From a maintenance perspective, the heavily damaged segments should receive greater attention because localized severe deterioration can affect road safety and accelerate the deterioration of adjacent pavement areas.

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International Roughness Index (IRI) Profile and Pavement Surface Roughness

The International Roughness Index (IRI) assessment was conducted using the RoadLab smartphone application to evaluate pavement surface roughness along the 3,000 m Gunungwungkal–Sumberrejo road section. The measurement was performed at 100 m intervals, resulting in IRI observations for 30 segments in each survey direction. The RoadLab application recorded pavement roughness based on vehicle movement during the field survey, providing an IRI value that represented the surface unevenness of each segment. The East–West measurement produced IRI values ranging from 2.29 to 11.96 m/km across the 30 segments. The highest IRI value in this direction was recorded in Segment 5 at 11.96 m/km, whereas the lowest value was recorded in Segment 27 at 2.29 m/km. The variation indicates that pavement smoothness differed substantially along the road section. These measurements were subsequently classified according to the road-condition categories used in the study.

Table 4. IRI Values from East to West

Segment	Distance (m)	Speed (km/h)	IRI	Road Condition
1	100	20	5.33	Fair
2	200	26	9.24	Lightly Damaged
3	300	22	6.30	Fair
4	400	22	7.46	Fair
5	500	22	11.96	Lightly Damaged
6	600	26	3.62	Good
7	700	27	7.33	Fair
8	800	26	9.07	Lightly Damaged
9	900	27	9.22	Lightly Damaged
10	1000	28	10.59	Lightly Damaged
11	1100	28	7.55	Fair
12	1200	29	8.12	Lightly Damaged
13	1300	32	8.01	Lightly Damaged
14	1400	28	8.78	Lightly Damaged
15	1500	29	7.57	Fair
16	1600	28	4.83	Fair
17	1700	29	6.61	Fair
18	1800	27	4.87	Fair
19	1900	25	4.66	Fair
20	2000	24	3.58	Good
21	2100	25	4.57	Fair
22	2200	28	4.29	Fair
23	2300	28	4.54	Fair
24	2400	25	6.93	Fair
25	2500	25	3.56	Good
26	2600	28	3.03	Good
27	2700	29	2.29	Good
28	2800	25	3.40	Good
29	2900	27	3.77	Good
30	3000	28	3.49	Good

The East–West IRI profile demonstrates that several segments experienced relatively high surface roughness. Segments 2, 5, 8, 9, 10, 12, 13, and 14 were classified as lightly damaged, with IRI values generally exceeding 8 m/km. Segment 5 exhibited the highest IRI value of 11.96 m/km, followed by Segment 10 at 10.59 m/km and Segment 2 at 9.24 m/km. In contrast, Segments 25–30 recorded comparatively low IRI values ranging from 2.29 to 3.77 m/km and were classified as good. The concentration of higher IRI values in the earlier and middle portions of the road indicates that surface unevenness was not uniformly distributed along the survey route. High roughness values can reduce driving comfort because greater longitudinal unevenness causes more pronounced vehicle vibration during travel. The East–West profile therefore identifies specific segments where pavement smoothness is substantially lower than that of the later road sections. These findings provide a functional perspective that complements the visible distress information obtained through the SDI assessment.

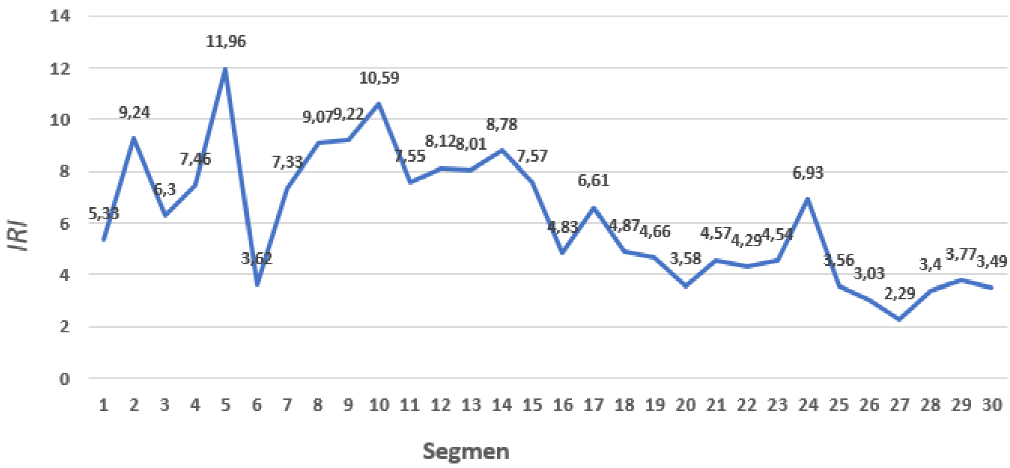

Figure 2. IRI Profile Graph of Gunungwungkal–Sumberrejo Road, East–West Direction

The IRI measurement was also conducted in the opposite West–East direction to examine pavement roughness from the reverse travel path. The results show that IRI values in this direction ranged from 3.49 to 9.62 m/km across the 30 segments. The lowest value was recorded at Segment 30 with an IRI of 3.49 m/km, while the highest value occurred at Segment 12 with an IRI of 9.62 m/km. Segments 15, 13, 12, 11, and 9 recorded relatively high values and were classified as lightly damaged, with IRI values of 8.10, 8.47, 9.62, 8.13, and 8.87 m/km, respectively. Meanwhile, the initial reverse-direction segments, particularly Segments 30, 29, and 27, showed comparatively low IRI values and were classified as good. The remaining segments were predominantly classified as fair, indicating moderate roughness along much of the survey route. The West–East measurements therefore show a different distribution of roughness compared with the East–West measurements, although several locations exhibited similar patterns of elevated IRI.

Table 5. IRI Values from West to East

Segment	Distance (m)	Speed (km/h)	IRI	Road Condition
30	100	24	3.49	Good
29	200	27	3.77	Good
28	300	25	4.63	Fair
27	400	26	3.84	Good
26	500	24	4.80	Fair
25	600	27	6.00	Fair
24	700	24	5.15	Fair
23	800	23	6.89	Fair
22	900	24	4.66	Fair
21	1000	29	6.50	Fair
20	1100	31	4.57	Fair
19	1200	28	5.45	Fair
18	1300	28	6.05	Fair
17	1400	26	7.43	Fair
16	1500	28	6.73	Fair
15	1600	28	8.10	Lightly Damaged
14	1700	25	6.15	Fair
13	1800	25	8.47	Lightly Damaged
12	1900	27	9.62	Lightly Damaged

11	2000	28	8.13	Lightly Damaged
10	2100	25	7.88	Fair
9	2200	20	8.87	Lightly Damaged
8	2300	20	7.25	Fair
7	2400	21	6.01	Fair
6	2500	24	7.29	Fair
5	2600	24	7.32	Fair
4	2700	21	4.22	Fair
3	2800	24	6.41	Fair
2	2900	21	7.02	Fair
1	3000	22	6.27	Fair

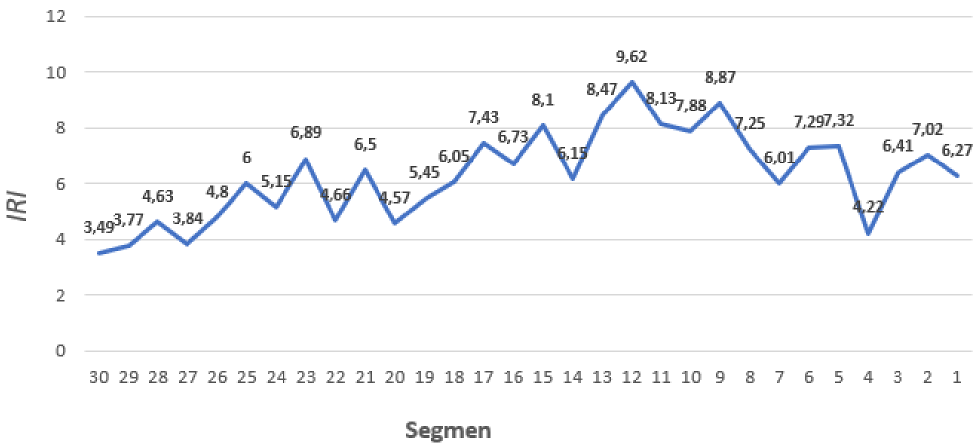

Figure 3. IRI Profile Graph of Gunungwungkal–Sumberrejo Road, West–East Direction

The comparison of the two IRI measurement directions indicates that pavement roughness varied according to both location and survey direction. The original analysis reported that the West–East direction generally showed a relatively smoother pavement condition than the opposite direction, allowing road users to experience comparatively better riding comfort. The difference between directions is evident in several segments where the IRI values changed considerably despite representing the same physical road section. Such variation may reflect differences in the measured vehicle trajectory, lane position, or localized pavement irregularities encountered during each run. The findings demonstrate that repeated directional measurements can provide a more comprehensive representation of pavement roughness than relying on a single measurement path. The overall IRI assessment reported an average roughness value of 0.4 m/km and classified the road condition as good. The segment-level distribution, however, still identified several sections with fair and lightly damaged conditions, indicating that localized roughness remained present despite the favorable overall assessment.

Table 6. Recapitulation of IRI Condition Percentage for Segments 1–30

No.	Surface Condition	Number of Segments	Percentage
1	Good	8	27%
2	Fair	14	47%
3	Lightly Damaged	8	27%
4	Heavily Damaged	0	0%
Total		**30**	**100%**

The distribution of IRI-based pavement conditions shows that 27% of the segments were classified as good, 47% as fair, 27% as lightly damaged, and none as heavily damaged. The largest proportion was therefore represented by the fair category, indicating that moderate surface roughness was the dominant condition across the 30 observed segments. The presence of 27% lightly damaged segments also demonstrates that a substantial portion of the road experienced higher roughness levels requiring attention. In contrast, the absence of heavily damaged segments indicates that the roughness measurement did not identify any section falling into the most severe IRI condition category. The IRI results therefore present a more favorable pavement-condition profile than the SDI results, particularly because the SDI assessment identified several heavily damaged segments. This difference suggests that visible surface distress and measured surface roughness do not necessarily develop at the same intensity or at the same locations. The contrasting distributions of SDI and IRI provide an important basis for the subsequent analysis of the relationship between the two pavement-condition indicators.

Relationship between SDI and IRI and Integrated Pavement Condition Evaluation

The relationship between the Surface Distress Index (SDI) and International Roughness Index (IRI) was analyzed to determine the degree of association between visible pavement distress and surface roughness. The analysis used the SDI and IRI values obtained from the 30 road segments covering STA 0+000–3+000. The correlation coefficient obtained from the calculation was **0.355**. Based on the classification used in the original analysis, this value indicates a weak relationship between SDI and IRI. The result indicates that increases in visible pavement distress were not consistently accompanied by proportional increases in measured pavement roughness. This condition is also reflected in several segments where relatively high SDI values were accompanied by different levels of IRI. The finding demonstrates that SDI and IRI provide different but complementary perspectives for evaluating pavement condition. Therefore, the two indicators need to be considered together when assessing the overall condition of the road section.

The weak correlation can be observed from the variation between SDI and IRI values across individual segments. Segment 8 recorded the highest SDI value of 335 and an IRI value of 9.07, while Segment 5 had a considerably lower SDI value of 75 but the highest IRI value of 11.96. Segment 9 provides another contrasting condition because its SDI value was 0 while its IRI value reached 9.22. Similarly, Segment 23 recorded an SDI value of 40 and an IRI value of 4.54, whereas Segment 3 recorded an SDI value of 245 and an IRI value of 6.30. These differences indicate that visible surface distress and longitudinal roughness did not always increase simultaneously at the same locations. The result is consistent with the purpose of using both SDI and IRI, because SDI emphasizes observable pavement distress whereas IRI represents pavement roughness. The combined interpretation can therefore provide a broader representation of pavement performance than either indicator considered independently.

Table 7. Correlation Analysis of SDI and IRI Data of Gunungwungkal–Sumberrejo Road

Segment	SDI (x)	IRI (y)	(x)(y)	$(x)^2$	$(y)^2$
1	10	5.33	53.30	100	28.41
2	165	9.24	1524.60	27225	85.38
3	245	6.30	1543.50	60025	39.69
4	235	7.46	1753.10	55225	55.65
5	75	11.96	897.00	5625	143.04
6	85	3.62	307.70	7225	13.10
7	225	7.33	1649.25	50625	53.73
8	335	9.07	3038.45	112225	82.26
9	0	9.22	0	0	85.01
10	75	10.59	794.25	5625	112.15
11	10	7.55	75.50	100	57.00
12	80	8.12	649.60	6400	65.93
13	10	8.01	80.10	100	64.16
14	10	8.78	87.80	100	77.09
15	10	7.57	75.70	100	57.30
16	5	4.83	24.15	25	23.33
17	0	6.61	0	0	43.69

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18	25	4.87	121.75	625	23.72
19	25	4.66	116.50	625	21.72
20	40	3.58	143.20	1600	12.82
21	15	4.57	68.55	225	20.88
22	0	4.29	0	0	18.40
23	40	4.54	181.60	1600	20.61
24	0	6.93	0	0	48.02
25	0	3.56	0	0	12.67
26	15	3.03	45.45	225	9.18
27	0	2.29	0	0	5.24
28	15	3.40	51.00	225	11.56
29	5	3.77	18.85	25	14.21
30	75	3.49	261.75	5625	12.18

The integrated pavement evaluation was then conducted by combining SDI and IRI results to determine the appropriate treatment for each segment. The treatment determination was based on the level of pavement distress and roughness identified through the two assessment methods. The original study used the Road Condition Survey guidelines for routine road maintenance as the basis for determining pavement condition and treatment type. The resulting classification allowed each segment to be associated with a specific intervention, including routine maintenance, periodic maintenance, rehabilitation, or reconstruction. Segments with relatively good pavement conditions were generally assigned routine or periodic maintenance, while segments with more substantial deterioration were assigned rehabilitation or reconstruction. This approach allows maintenance decisions to be differentiated according to the actual condition of individual road segments. The resulting treatment recommendations are presented in Table 8.

Table 8. Recapitulation of Road Condition and Road Treatment Types for Gunungwungkal–Sumberrejo Road, Pati, Segments 1–30

Segment	SDI	IRI	Surface Condition	Treatment Type
1	10	5.33	Good	Periodic Maintenance
2	165	9.24	Heavily Damaged	Rehabilitation
3	245	6.30	Heavily Damaged	Reconstruction
4	235	7.46	Heavily Damaged	Reconstruction
5	75	11.96	Fair	Reconstruction
6	85	3.62	Fair	Periodic Maintenance
7	225	7.33	Heavily Damaged	Reconstruction
8	335	9.07	Heavily Damaged	Reconstruction
9	0	9.22	Good	Rehabilitation
10	75	10.59	Fair	Rehabilitation
11	10	7.55	Good	Periodic Maintenance
12	80	8.12	Fair	Rehabilitation
13	10	8.01	Good	Rehabilitation
14	10	8.78	Good	Rehabilitation
15	10	7.57	Good	Periodic Maintenance
16	5	4.83	Good	Periodic Maintenance
17	0	6.61	Good	Periodic Maintenance
18	25	4.87	Good	Periodic Maintenance
19	25	4.66	Good	Periodic Maintenance
20	40	3.58	Good	Routine Maintenance
21	15	4.57	Good	Periodic Maintenance
22	0	4.29	Good	Periodic Maintenance
23	40	4.54	Good	Periodic Maintenance
24	0	6.93	Good	Periodic Maintenance

25	0	3.56	Good	Routine Maintenance
26	15	3.03	Good	Routine Maintenance
27	0	2.29	Good	Routine Maintenance
28	15	3.40	Good	Routine Maintenance
29	5	3.77	Good	Routine Maintenance
30	75	3.49	Fair	Periodic Maintenance

The segment-level treatment results show that the most intensive interventions were concentrated in locations with heavily damaged pavement conditions. Segments 3, 4, 7, and 8 were assigned reconstruction, while Segment 2 was assigned rehabilitation based on the combined SDI and IRI assessment. Segment 5 was also assigned reconstruction despite its fair surface-condition classification because it recorded the highest IRI value of 11.96 m/km. In contrast, Segments 20 and 25–29 were assigned routine maintenance because their pavement conditions and measured indices indicated comparatively lower deterioration. The average SDI and IRI values across the 30 segments were reported as 61 and 6.1523, respectively, with the overall surface condition classified as good and periodic maintenance selected as the general treatment. These results demonstrate that the recommended intervention differs substantially between individual segments even when the overall road condition is considered relatively favorable.

Table 9. Comparison of Road Pavement Conditions

Category	SDI	IRI	Difference (SDI − IRI)
Good	67%	27%	40%
Fair	17%	47%	30%
Lightly Damaged	0%	27%	27%
Heavily Damaged	17%	0%	17%
Average percentage difference between SDI and IRI			**28.5%**

Table 10. Percentage of Road Conditions and Treatment Programs for Gunungwungkal–Sumberrejo Road, Pati

Number of Segments	Condition	Treatment	Percentage
6	Good	Routine Maintenance	20%
11	Good	Periodic Maintenance	37%
3	Good	Rehabilitation	10%
2	Fair	Periodic Maintenance	7%
1	Fair	Reconstruction	3%
2	Fair	Rehabilitation	7%
0	Lightly Damaged	Rehabilitation	0%
4	Heavily Damaged	Reconstruction	13%
1	Heavily Damaged	Rehabilitation	3%
30	**Total**		**100%**

The treatment distribution confirms that periodic maintenance was the dominant intervention in the study section. A total of 37% of the segments were classified as good and assigned periodic maintenance, while 20% were classified as good and assigned routine maintenance. Another 10% of the segments were classified as good but required rehabilitation, indicating that surface-condition classification alone was not sufficient to determine treatment requirements. For the fair-condition segments, 7% were assigned periodic maintenance, 3% were assigned reconstruction, and another 7% were assigned rehabilitation. Among the heavily damaged segments, 13% required reconstruction and 3% required rehabilitation. Overall, the treatment distribution shows that maintenance needs were concentrated in specific locations rather than uniformly distributed throughout the 3,000 m road section.

CONCLUSION

Based on the research findings, the assessment of pavement conditions using the Surface Distress Index (SDI) showed an average SDI value of 200.83, which falls into the heavily damaged category. The SDI-based pavement condition distribution consisted of 67% good, 17% fair, 0% lightly damaged, and 17% heavily damaged segments. The most prominent pavement distresses observed along the Gunungwungkal–Sumberrejo road were cracking, potholes, patching, depression, and raveling, with severe deterioration concentrated in several segments. Meanwhile, the assessment using the International Roughness Index (IRI) with the RoadLab application resulted in an average IRI value of 6.1523 m/km, indicating a generally fair level of pavement roughness. Based on the IRI assessment, 27% of the segments were classified as good, 47% as fair, 27% as lightly damaged, and 0% as heavily damaged, showing that moderate roughness was the dominant condition. The correlation analysis between SDI and IRI produced a coefficient of 0.355, indicating a weak positive relationship between visible pavement distress and pavement roughness. This result demonstrates that SDI and IRI describe different but complementary aspects of pavement performance and should therefore be considered together in evaluating road conditions.

The integrated assessment of SDI and IRI indicates that the overall pavement condition of the Gunungwungkal–Sumberrejo road section in Pati was classified as generally good, with an average SDI of 61 and an average IRI of 6.1523 m/km. The results show that pavement conditions varied considerably between segments, meaning that maintenance priorities should be determined based on the actual condition of each segment rather than solely on the overall average. Segments with severe deterioration, particularly Segments 3, 4, 7, and 8, were recommended for reconstruction, while Segment 2 was recommended for rehabilitation. Segment 5 was also recommended for reconstruction because it recorded the highest IRI value of 11.96 m/km, despite its fair SDI-based condition. In general, the treatment recommendations consisted of routine maintenance, periodic maintenance, rehabilitation, and reconstruction according to the severity of pavement deterioration. The treatment distribution in the study showed 20% routine maintenance, 37% periodic maintenance, 20% rehabilitation, and 23% reconstruction, with periodic maintenance being the dominant treatment. Therefore, the combination of SDI and IRI provides a more comprehensive basis for determining pavement maintenance strategies and prioritizing interventions along the Gunungwungkal–Sumberrejo road section.

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