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# Analysis and Development of Surface Distress Index Modified Based on Pavement Condition Index Criteria for Pavement Evaluation

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**Abstract**

The surface distress index (SDI) method has been used in Indonesia to assess road conditions, especially for areas with limited access, inadequate equipment, and limited local resources, which cause inaccuracies in the resulting pavement condition assessment. This research aims to develop a more accurate and efficient pavement condition assessment model based on three types of damage: cracks, potholes, and rutting. To generate accurate SDI values, we adopt and modify the deduct value (DV) curve based on the PCI method to determine the corresponding damage weight and the new road condition assessment. Based on the research results, the three modified SDI damage models showed an average accuracy value of 90%, which means that there is a good match between the models and the conditions on the ground, which is reinforced by the analysis of the mean absolute percentage error (MAPE) and root mean squared error (RMSE) values. In addition, the resulting development includes new assessment criteria and parameters, such as customized DV curve models and specific damage equations, condition index, condition rating, and maintenance types. Which in turn can support more effective and efficient infrastructure management and maintenance.

*Keywords:* Road Condition; Surface Distress Index; Pavement Condition Index; Deduct Value Curve.

## 1. Introduction

Road condition assessment is a significant component of the pavement management system. The assessment involves three main factors: damage data collection, pavement condition analysis, and maintenance planning. The assessment process involves three main factors: damage data collection, pavement condition analysis, and maintenance planning [1]. In other words, it plays a role in determining the type of pavement maintenance types [2], the allocation of limited financial resources [3], and other limited local resources [4]. Shtayat et al. (2020) [5] emphasized that the indicators utilized for evaluating pavement quality should be precise and consistent throughout the evaluation process. Assessment conditions pavement helps identify the nature and extent of deterioration [5], describe the current conditions [6], and predict future conditions [4]. These assessments are essential for effective road maintenance management [6, 7].

In Indonesia, various indicators and methodologies have been employed to evaluate pavement conditions, including the road condition index (RCI), international roughness index (IRI), present serviceability index (PSI), surface distress index (SDI), and pavement condition index (PCI). To date, SDI is the most popular method used in

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various road networks in Indonesia [8-11]. SDI can provide convenience in the measurement process, data collection, and calculation process, and the results can provide recommendations on the type of maintenance required. The SDI method analysis focuses on three types of deterioration observed during road segment examination: cracking, potholes, and rutting, as delineated in the road condition survey manual (SMD-03/RCS) of the Indonesian Integrated Road Management System (IIRMS) in 2011 [12, 13]. Moreover, SDI is still in use as one of the technical data criteria in the proposed allocation of funds for road infrastructure, especially local roads in Indonesia. While SDI provides convenience, it is crucial to realize its limitations, as noted by Setiadji et al. (2019) [14], especially in identifying crack damage types and distinguishing between potholes and rutting [11]. In addition, the SDI original also has limitations in describing the characteristics of damage types, so the multipliers and weights used in the calculation of the SDI method only depend on three types of damage that are calculated cumulatively [12, 13]. For example, suppose a road section is identified as having only one damage in the SDI method. In that case, the condition assessment result will differ from those with multiple damages. This results in less accurate and consistent assessments when compared to field conditions.

In this paper, to address SDI's limitations, the PCI method is employed as a benchmark for adjusting SDI since the parameters in the PCI method provide a comprehensive assessment conducted in several countries. Also, this method allows us to assess pavement conditions by considering the type of deterioration, the severity of the damage, and the density of damage numerically [4, 6, 11-16]. The PCI method approach itself is considered to provide a measurable assessment, so it is widely used as a reference by several countries in assessing pavement conditions [17, 18]. However, the PCI method also has some disadvantages, namely related to the cost of surveys in data collection, which is expensive, and analysis of the results is quite complicated [4].

This research aims to address the gap between SDI and PCI by trying to improve and modify a method of assessment that becomes more accurate, efficient, and easy to implement and that can be adapted to regional characteristics. The main objective of this study is to develop the SDI pavement condition assessment model that considers three types of deterioration, cracking, potholes, and rutting, by modifying the deduct value based on the PCI model parameters to determine the corresponding damage weight and the new road condition assessment. In addition, the outcomes of this study are expected to provide input and suggestions to regional road operators in Indonesia regarding the methods of accurately and consistently modifying SDI to deliver condition assessments consistent with actual situations in the field. Furthermore, the results of this study can also serve as a reference for other countries facing the same issues and characteristics as Indonesia.

## 1.1. The Original SDI Criteria

IIRMS (2011) [12] developed SDI, among the most popular measurements and methods utilized across all road authorities in Indonesia. SDI has been developed by the Directorate General of Highways (DGH), a part of the Indonesian Ministry of Public Works and Housing, and incorporates among all of the database parts for entry of road condition data into the road network management system in Indonesia, which is known as IIRMS. According to IIRMS (2011) [12] in the road condition survey manual (SMD-03/RCS), the effectiveness of SDI evaluation is defined by three deterioration criteria: cracking (width and level of cracking), potholes (number of holes), and rutting caused by decreasing the load of vehicle load ruts on a section of the pavement surface [12, 13]. In particular, it makes it more straightforward for field surveyors to identify the measurement and type of damage; the data-gathering method is visual and subjective, while calculation processes are quick, ensuring that it does not take longer. Besides that, in determining the condition category and type of pavement treatment, the SDI value [13] could be associated with the IRI [19].

Table 1 presents the parameters and values obtainable in the original SDI calculation derived through composite accumulation. These types of damage contribute significantly to the SDI assessment, depending on the ratio of damage area to the measured area (density). The index is the cumulative contribution of multiple damages caused by the three types of damage across 100 meters. According to the SDI stages in Table 1, the minimum SDI value that could have been reached is 0, while the maximum SDI value is 325. The SDI calculation procedure is accumulative since the result at stage 2 (SDI 2) is influenced by SDI 1, indicating that empirical SDI calculation should not be employed independently. Given the result of each parameter and the value of each damage, it can be seen that rutting contributes barely any of the other damages assessed, while potholes lead a great deal [13, 20]. Therefore, this process is not straightforward and encourages engineers and field employees to visually modify pavement conditions' measurements, calculations, and justifications, whereby subjectivity plays a significant role when assessing road conditions.

**Table 1. Stages of the SDI Analysis**

| Distress Type | Parameter | Category | SDI Value |
|---|---|---|---|
| Crack | Total area of crack (crack depth + other crack) | None | SDI 1 = 0 |
| | | < 10 % | SDI 1 = 5 |
| | | 10 - 30 % | SDI 1 = 20 |
| | | > 30 % | SDI 1 = 40 |
| | Average crack with (mm) | None | SDI 2 = SDI 1 |
| | | < 1 mm | SDI 2 = SDI 1 |
| | | 1 - 3 mm | SDI 2 = SDI 1 |
| | | > 3 mm | SDI 2 = SDI 1*2 |
| Potholes | Total number of potholes | None | SDI 3 = SDI 2 |
| | Total number of potholes | < 10 / km | SDI 3 = SDI 2 + 15 |
| | | 10 - 50 / km | SDI 3 = SDI 2 + 75 |
| | | > 50 / km | SDI 3 = SDI 2 + 225 |
| Rutting | Average rut depth (cm) | None | SDI 4 = SDI 3 |
| | Average rut depth (cm) | < 1 cm | SDI 4 = SDI 3 + 2.5 |
| | Average rut depth (cm) | 1 - 3 cm | SDI 4 = SDI 3 + 10 |
| | | > 3 cm | SDI 4 = SDI 3 + 20 |

The criteria conditions from the SDI assessment outcome have been classified into four types, as shown in Figure 1. These are Good (G), Fair (F), Light damage (LD), and Major damage (MD), to determine the type of maintenance necessary to keep up the condition of the pavement, which is associated with rehabilitation based on the result of the SDI condition classifications in Table 2.

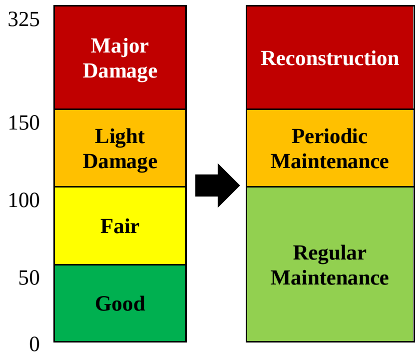



**Figure 1. Original SDI Criteria of Damage Type**

**Table 2. SDI Modified Properties Criteria**

| No. | Distress Type | Description Parameters |
|---|---|---|
| 1 | Cracking | Total area of cracking |
| 2 | Potholes | Potholes diameter |
| 3 | Rutting | Width and length of rutting |

## 1.2. The Original PCI Criteria

According to Shahin (2005) [19], the pavement condition index (PCI) is an indicator with a value from 0-100 used to assess the general condition of the pavement. PCI is a rating system that measures the functioning condition of a pavement road; the lower the PCI value, the poorer that pavement condition road. As with the PCI method, the severity of pavement deterioration is driven by three significant factors: deterioration type, severity of damage, and density. The concept of the PCI method itself is the deduct value (DV) used in the damage data analysis process, which shows the impact of damage on pavement condition [21]. When calculating the PCI, it is essential to consider these DV adjustments to accurately represent the required general pavement condition and maintenance and the rehabilitation strategy [22, 23]. The PCI method identifies 19 types of pavement damage, as shown in Figure 2, each of which is classified by severity and density. Which is used to determine the deduct value. DV is a factor used to identify the degree/size of the effect that combines each distress type, severity level, and distress density found in the pavement condition.

PCI is an indicator of a number that measures the condition of a pavement surface. PCI provides a numerical rating of segments across a road network. All identified issues on the pavement are assessed based on their type, severity, and length. Seven kinds of PCI evaluation conditions are good, satisfactory, fair, poor, very poor, severe, and failed. Furthermore, the PCI treatment method is defined by the PCI value, which is classified into three treatment categories: preventive maintenance, rehabilitation, and reconstruction. However, there are several issues with the utilization of PCI in Indonesia. It tends not to be directly proportional to the capabilities of available resources, such as the limitations of utilizing PCI in data collection, which are too expensive [4, 15]; the analysis process gets complicated [11]; the lack of validity of field employees leads to gaps through outcomes, along with it could be challenging to carry out in particular areas [24]. In addition, many situations related to pavement condition evaluation in Indonesia require further study [25].

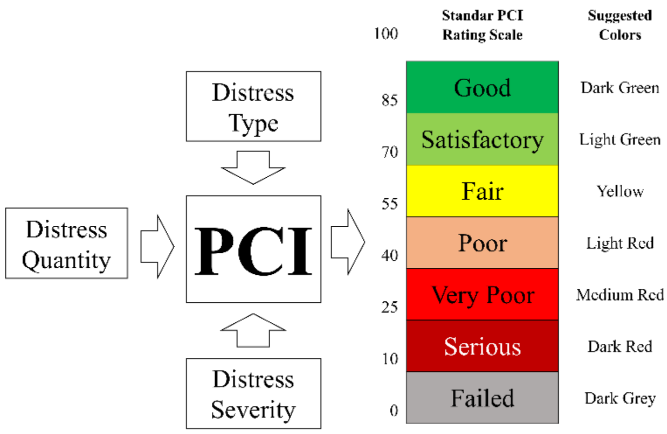



**Figure 2. The Principle of the Original PCI Method [19]**

## 2. Research Methodology

The research is divided into three phases, as shown in Figure 3; the initial phase is to analyze secondary data, which will be applied to the model. The second phase generates a DV curve using secondary data processing. Furthermore, in the last phase, simulation and verification of the established modified SDI model are carried out. The study was conducted using secondary data from a database of regional roads from the Regional Infrastructure Facilitation Centre in The Road Sector, Secretariat General of the Indonesian Ministry of Public Works and Housing. Secondary data includes road information by state, prior SDI analysis data, images of road damage, and field measurement data.

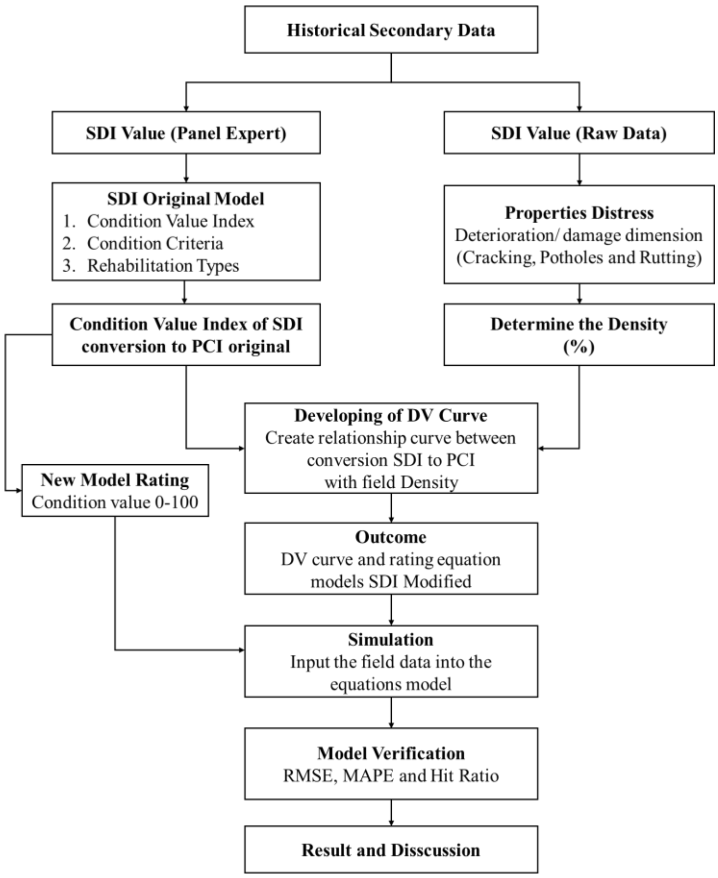



**Figure 3. Research Methodology**

The secondary data is analyzed in a couple of forms that apply raw data as parameters to develop a model based on three types of damages and the original SDI method a panel expert generated. The two approaches are then used to construct a DV curve and develop a modified SDI model. The modified SDI model being established depends on three types of damage by assessing the three properties included in the PCI model criteria: Size of the damage, density of the deterioration (%), and deduct value (DV).

The locations were selected based on the characteristics and completeness of the data obtained during the survey. Specifically, the damage conditions varied in the field, and we could describe the damage conditions in Indonesia's central and eastern regions. Other characteristics included geographical factors, unstable soil structure, high rainfall, local variations, and pavement characteristics [26]. Factually, the average problem in Indonesia is that there is still a low quality of pavement construction implementation and a sharp gap between the available budget and the length of roads to be maintained. The locations include East Kalimantan Province, Pasangkayu District (West Sulawesi Province), and South Sorong District (West Papua), as shown in Figure 4.

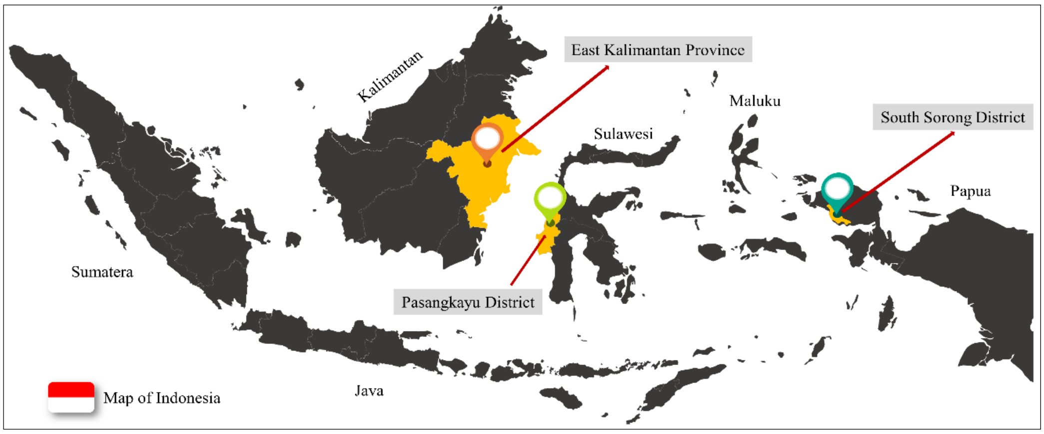



**Figure 4. Location of case study**

## 2.1. SDI Modified Criteria from Panel Expert

The first stage is to obtain the formula for creating the DV function with the SDI values from the regional road expert or panel expert. The association organization of the expert panel throughout has been assumed to be accurate (with minimum errors). The panel expert assessment includes verifying the relevancy of field data and analyzing SDI estimation, as well as running validation on the reliability of the information on road management recommendations in Indonesia regarding a regular and organized system, from regional to the highest level of government. Assessments are close to each other [27, 28].

Previous studies on airport pavement case studies in South Korea employed expert recommendations to generate DV and PCI model modification factor values. The findings show that applying the outcomes of the PCI standard assessment method established in America can sometimes lack significant findings while analyzing the condition of airport pavement in Korea [23]. This indicates that the shape of the DV curve function needs to be modified based on geographical conditions, the type of damage, and the level of damage that appears in the field, particularly in Indonesia. Furthermore, the second stage for creating the modified SDI rating is the original SDI index 0-325 provided in IIRMS (2011), modified into a condition assessment index that ranges from 0-100 while seven condition classifications and types of rehabilitation as stated in Shahin et al. (2005) [19] and ASTM D-6433 [29]. Figure 5 represents the modified SDI index by applying an assessment from the adjusted PCI. To obtain a new rating for SDI modified as shown in Figure 5. (c) a model was developed from field survey data in the study area.

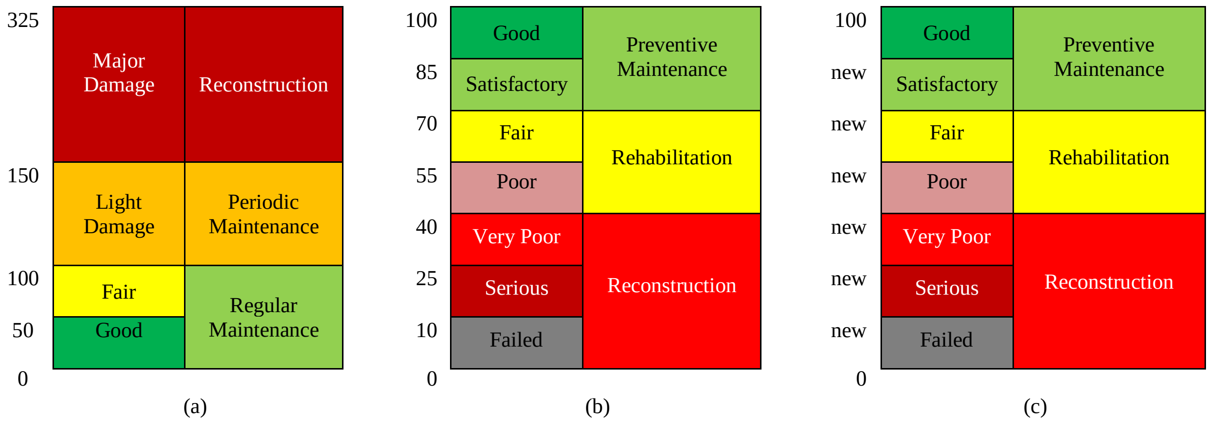



**Figure 5. The Pavement Condition Rating: Original SDI (a), Original PCI (b), and SDI Modified (c)**

DV creation is calculated from the total SDI value and the maximum contribution of SDI damage, 325 of the cumulative results of provided cracking, potholes, and rutting damage. Subsequently, the maximum value of 325 is converted into the PCI scale, which is 100, as shown in Equation 1.

$$SDI_{converted} = \frac{\text{SDI value of panel expert} \times 100}{325} \tag{1}$$

where SDI value of panel expert is the result of the latest SDI analysis of the regional road database, 100 is maximum scale of PCI original, and 325 is maximum scale of SDI original.

The new SDI condition rating assessment has been adjusted and modified into a condition assessment index ranging from 0 to 100, including seven condition categories and maintenance methods, as stated by Shahin et al. (2005) [19] and ASTM D-6433 [29]. From the obtained rating, effective road segment prioritization can be done for maintenance scheduling [27].

## 2.2. Characteristics of SDI Modified Criteria

This study's empirical model requirements must be modified to accommodate local conditions [22]. Several property criteria were created to simplify data collection and estimation. The parameters employed in the modified SDI criteria are shown in Table 2. Several evaluations from the original SDI and PCI were applied to determine the damage density (%) to make measuring the damage in the field less complicated. First, for the type of crack damage, the original SDI parameters properties remain used to determine the total area of crack damage, which is identical to the PCI damage density assessment. Second, the pothole damage refers to the original PCI damage parameters, the potholes' diameter. To enhance the accuracy of the evaluation at the first stage of analyzing potholes, the determination factor does not necessarily count the number of holes in each kilometer, as in the original SDI.

Third, the type of rutting damage applies the damage density parameters from the original PCI depending on the width and length of the rutting damage. Following that, Eq. (1) shows the method for determining damage density using the original PCI criteria calculation for each type of damage, such as cracking, potholes, and rutting. Using Eq. (1), the SDI-modified assessment criteria can provide more detailed results than the calculation and assessment of the original SDI.

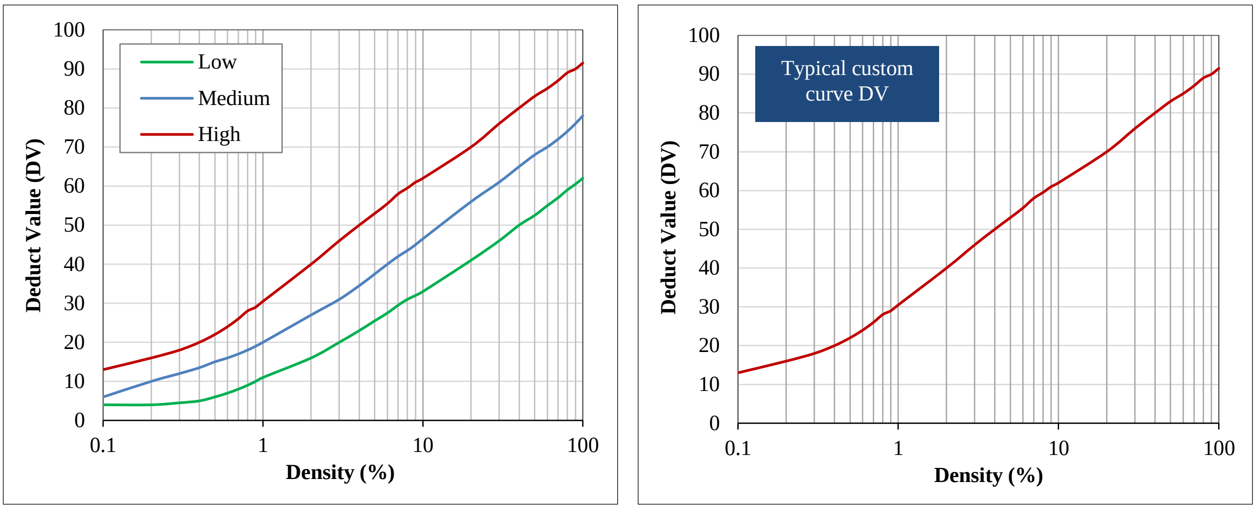
$$\text{Density (\%)} = \frac{\text{Total Area of Damage } (m^2)}{\text{Area of The Test Segment } (m^2)} \tag{2}$$

## 2.3. DV Curve by SDI Modified Criteria

Shahin (2005) [19] explains DV as a form of contributing to the aspect that determines the degree/size of an effect, which involves each type of damage, the level of severity, and the density of damage identified in the pavement condition. DV has been established by pavement behavior, a suggestion from several qualified pavement experts, field measurements, and an assessment of the methods and definition of the type and degree of damage. In previous studies, DV curve development has been carried out to adapt to the area's conditions, as Cho et al. (2022) [23] conducted on the evaluation of airport pavement assessment in Korea. According to him, the development of the DV curve is considered more appropriate than the DV curve based on ASTM D534. However, it can be time-consuming to inspect large quantities, so it is worthwhile to develop a new DV curve simplification according to the conditions in Indonesia.

In principle, it is a DV or DV curve where a cumulative reduction value rating decreases the PCI value depending on the damage type, quantity, and severity, as shown in Figure 6-a. This indicates that the DV total has been modified depending on the number and value of the deducted, and the corrected value is removed from 100 for calculating the PCI value [21, 22, 28, 29]. The original PCI curve model was based on severity levels, such as low (l), medium (m), and high (h). This method is complicated and requires time and expertise. To simplify it, we developed new curves of combined severity level for each damage from the results of each field-dominated damage. An illustration of the new curve is shown in Figure 6-b.

Another researcher who developed the SDI model by modifying the DV curve is Setiadji (2019) [13]. In his research, crack types were classified into seven types according to the PCI method with three severity levels (low, medium, and high) [12]. However, similar to the PCI method, there is still a significant deviation between the assessment results and the actual condition. To reduce this, the DV curve needs to be adjusted so that the DV curve model formed can be consistent and can be applied on various regional roads. As mentioned earlier, the assessment procedure in the PCI method tends to be complicated in determining each type of damage in the field. So, in this study, the assessment process is simplified but still in accordance with the initial concept regarding the types and characteristics of the damage.




(a) (b)

**Figure 6. Typical DV Curve From (a) Original PCI [28], (b) New DV curve model for SDI Modified**

## 3. Result and Discussion

### 3.1. SDI Modified for Crack Assessment Model

The modified SDI model was created by utilizing the DV curve of the PCI model, which was determined by field data results. Figure 6-b illustrates the created curve applied for calculating the DV value for cracking while not considering the severity level provided by the PCI method [28]. The field data results are described on a scatter diagram with a logarithmic scale on the axis, and a polynomial curve is positioned on their points to create a new curve [30]. The generated best equation developed in the cracking model is the following polynomial, as shown in Equation 2.

$$y = -0.0774x^2 + 3.9649x + 22.171 \quad (2)$$

where $y$ is New deduct value, $x$ is the logarithm of distress density; all cracking, and $R^2$ is the coefficient of correlation; all severity.

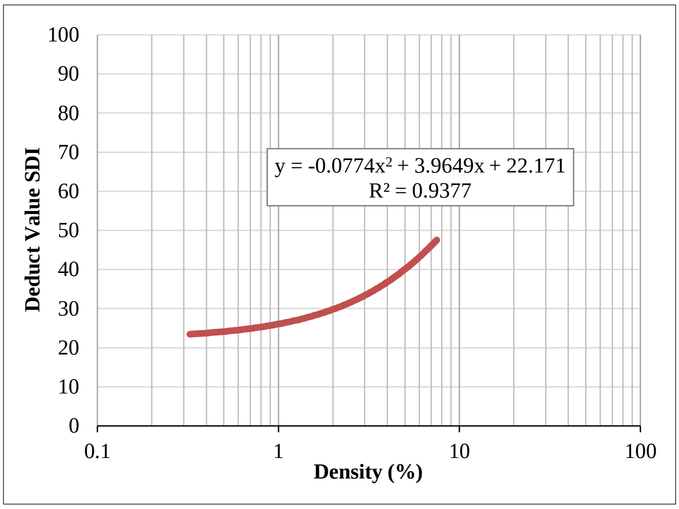



**Figure 7. New DV curve model for cracking**

In the form of the new assessment model, the cracking damage type is generated by conducting a regression analysis of the DV value and the density of the cracking damage type, which results in Equation 3, where the density used is based on the total area of cracking damage by representing all types of cracking combined (alligator, block, edge, joint reflection, longitudinal/transverse and slippage cracking). This study's determination of crack classification uses a combined crack classification with the crack area parameter, in contrast to the model previously developed by Setiadji

(2019) [13], which classifies crack models based on six types of damage. So, the field application for damage identification is much simpler. Consequently, it is not suggested that all three condition indexes be combined; instead, a particular performance relationship for each damage index in density should be created. If the index combines all three conditions, it is suggested that the average results be eliminated and a single standard deviation be eliminated [30, 31]. The DV value utilized in developing the crack curve model is the DV value that has been reduced by 100 from the expert panel assessment, which is a modified PCI curve.

Based on the crack model development results, as shown in Figure 7. The modified DV value has a significant sensitivity value, as seen in the generated coefficient of determination ($R^2$) of 0,9377. The new SDI resulted from developing SDI criteria by modifying the PCI model's DV curve to obtain an assessment result that closely represents the field conditions. The SDI value resulting from adjusting the DV curve of the PCI model generates a new assessment index, as illustrated in Figure 5. The new SDI assessment for the cracking model resulted from developing SDI criteria by modifying the PCI model's DV curve to obtain an assessment result that closely represents the field conditions. The DV curve used in the modification is adapted to the type of damage to be assessed. The SDI value resulting from modifying the DV curve of the PCI model generates a new assessment index, as shown in Figure 8.

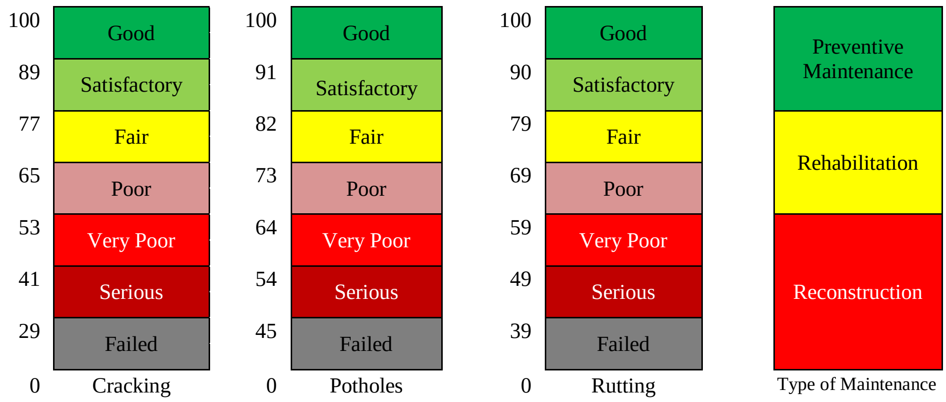



**Figure 8. The new rating based on SDI modified criteria**

The modified DV model is applied by adding the density (%) value from the crack measurement results in the field to verify that the model can be utilized. Furthermore, the process of determining the rating on the crack damage assessment is carried out to generate a new SDI value Equation 3. Furthermore, Equation 3 is also applied to determine the modified SDI value for other damage types, such as potholes and rutting.

$$\text{SDI}_{\text{Modified}} = C - (\text{DV}_{\text{i SDI}}) \tag{3}$$

where SDI is Surface distress index modified, $C$ is Model Constant for the maximum rating (100; Adoption PCI), $DV$ is Average total area of the type of damage; density of the kind of damage in a road section, $i$ is Type; cracking, potholes, rutting.

### 3.2. SDI Modified for Potholes Assessment Model

In the SDI assessment model for potholes, the DV in density estimations, the sensitivity value is presently determined by severity levels, including low (l), medium (m), and high (h), and neglects the number of holes/km as in the prior original SDI [13]. Thus, the width of the pothole damage is intended to represent the level of significance and sensitivity of the curve. The best result for the pothole model equation is shown (Equation 4):

$$y = 0.2023x^2 - 0.3734x + 35.766 \tag{4}$$

where $y$ is New deduct value, $x$ is the logarithm of distress density; potholes, and $R^2$ is the coefficient of correlation; all severity.

The following are the results of creating a new curve represented in Figure 9. Based on the results of model development on the modified DV curve, it can be seen that the pothole model (Equation 4) gives significant sensitivity, which can be shown from the $R^2$ value obtained of 0,8848. Therefore, the model can determine the new SDI assessment index. Furthermore, as with the crack damage, the value obtained from Equation 4 is then applied to generate a modified SDI value using Equation 3 by using the DV curve for the potholes damage type and developing a new assessment criteria index as shown in Figure 8.

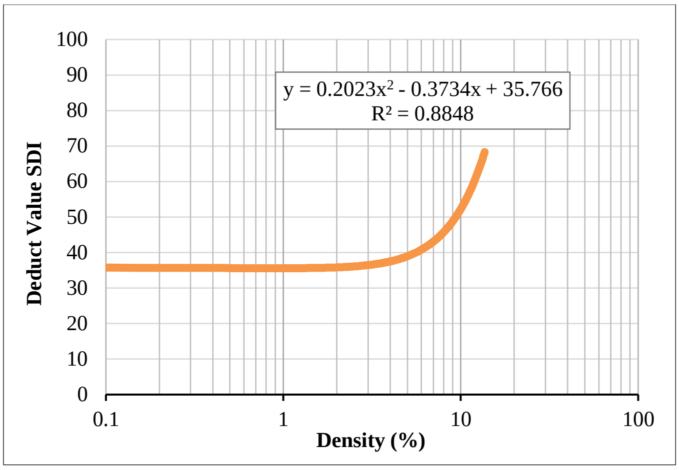



**Figure 9. New DV curve model for potholes**

### 3.3. SDI Modified for Rutting Assessment Model

According to a pair with the previous theories and methods, the findings of the SDI assessment equation are generated to represent the mean with a second-order polynomial structure. It is carried out by making it easier to add the density value into a formula in Equation 3. The generated equation created in the rutting model is provided in the form of the following polynomial, as shown in Equation 5.

$$y = -0.0171x^2 + 0.8052x + 27.33 \tag{5}$$

where $y$ is New deduct value, $x$ is the logarithm of distress density; rutting, and $R^2$ is the coefficient of correlation; all severity.

The rutting assessment curve model is shown in Figure 10 indicates that the model generated has a coefficient of determination ($R^2$) of 0.8658, lower than the cracking model of 0.9377 and potholes of 0.8848. That is because the quality and the characteristics of the pavement on regional roads made this sort of damage rare in the field. Thus, the rutting data, such as cracking and potholes, lacks significant variation. Furthermore, as with both previous damage categories, the value obtained from Equation 5 is then utilized to generate a modified SDI value through Equation 3 using the DV curve for the rutting damage type.

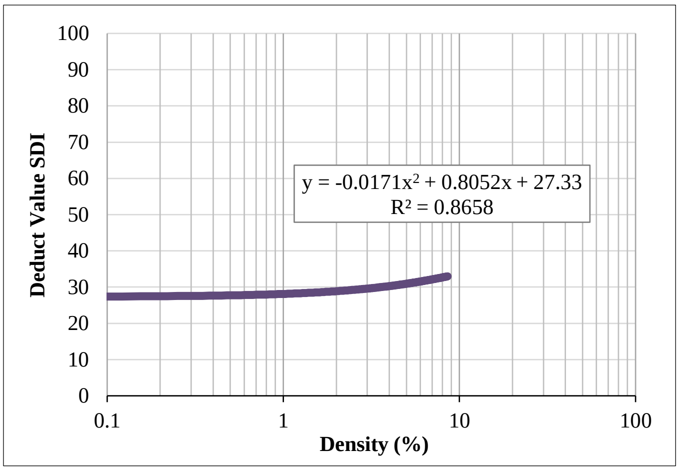



**Figure 10. New DV curve model for rutting**

### 3.4. Rating Condition for SDI Modified

The PCI method rating determines the modification of the damage condition value. Pavement conditions are assessed based on damage information obtained through field surveys and processed to generate an assessment using the PCI method [32]. The calculation of the SDI-modified value in this study led to simplifications in the PCI method assessment rating, which can be used in the field to determine pavement conditions. The SDI condition rating assessment has been adjusted and modified into a condition assessment index that ranges from 0-100, including seven condition categories and methods of maintenance, as stated by Shahin et al. (2005) [19] and ASTM D-6433 [29]. The SDI value for the three types of damage resulting from modifying the PCI model's DV curve generated a new assessment index, as shown in Figure 8. The proposed new rating from the modified SDI was then utilized to evaluate pavement conditions.

In this resulting calculation scheme, the pavement condition rating or SDI Modified rating based on cracking, potholes, and rutting was generated based on field data. In other words, the three indices, the average SDI Modified rating, were found to be in the range of 79-90 (satisfactory to good pavement condition), 69-79 (fair to satisfactory pavement condition), 58-69 (poor to fair pavement condition) and 0-48 (very poor to failed pavement condition).

### 3.5. Model and Verification Analysis

A simple method is applied to verify the developed model to evaluate the prediction result and model accuracy. Generally employed accuracy of model indicators are Mean Absolute Percentage Error (MAPE) and root Mean Squared Error (RMSE), which were used as statistical indicators [28]. This indicator could be employed to objectively evaluate model performance by measuring differences between predicted and actual results, which provides a greater comprehension of model error circumstances and possibilities for improvement [16, 33, 34].

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} = \sqrt{\frac{\sum_{t=1}^{n}(x_t - f_t)^2}{n}} \tag{6}$$

where n is value of the period, $x_t$ is actual value in the period of $t$, and $f_t$ is prediction value in the period of t.

$$\mathrm{MAPE} = \frac{\sum_{t=1}^{n}\left|\frac{x_t - f_t}{x_t}\right|}{n} \times 100\% \tag{7}$$

where n is value of the period, $x_t$ is actual value in the period of $t$ and $f_t$ is prediction value in the period of t.

The RMSE test evaluates model performance regarding suitability or prediction data [18]. RMSE estimates the gap between the value predicted by the model and the actual value. Compared to MAPE, RMSE lacks a minimum standard value to assess model performance [35]. For simplicity, RMSE is a method for estimating bias in prediction models, as shown in Equation 6. The lower the MAPE value, the better the prediction model's capacity. At the same time, a range of values for MAPE could be applied as measuring data for the prediction model's capacity [36], as shown in Table 3.

**Table 3. MAPE Assessment Category**

| MAPE Range (%) | Category |
|---|---|
| < 10 | The prediction model is perfect |
| 10 - 20 | The prediction model is fair. |
| 20 - 50 | The prediction model is moderate. |
| > 50 | The prediction model is poor. |

The SDI assessment results from the expert panel were compared with the SDI value from the SDI-modified model to calculate the RMSE and MAPE. As verified by relevant agencies, the regional road database's SDI value for crack damage types was derived from the assessment in the previous section. As described in the last paragraph, the relevant agencies assessed and verified the SDI value for each damage type in the regional road database. The model verification results using the RMSE method show that the resulting value is close to zero, as shown in Table 4.

**Table 4. Model Assessment Verification**

| No. | Type of damage | RMSE | MAPE | |
|---|---|---|---|---|
| | | | Value | Category |
| 1 | Potholes (width) | 0.002 | 1.13 | Very good |
| 2 | Cracking (length) | 0.003 | 1.25 | Very good |
| 3 | Rutting (depth) | 0.002 | 0.81 | Very good |

RMSE values close to zero indicate a prediction model with high accuracy [37]. In addition, based on the resulting MAPE value, as shown in Table 4, the three models produce values <10%, which means that there is a good fit between this model and the actual values in the cracks, potholes, and rutting models. This is supported by the results of the model validation using the MAPE method, which produces the highest value compared with potholes and rutting [38]. Thus, the proposed model provides accurate results, is more practical, and saves time compared to previous SDI and PCI methods. Based on the model verification results, it is possible to implement this model in locations outside the study area, provided that the conditions are similar to road conditions in Indonesia regarding pavement type, weather, air temperature, and other supporting parameters. Figure 11 illustrates the steps involved in applying the modified SDI.

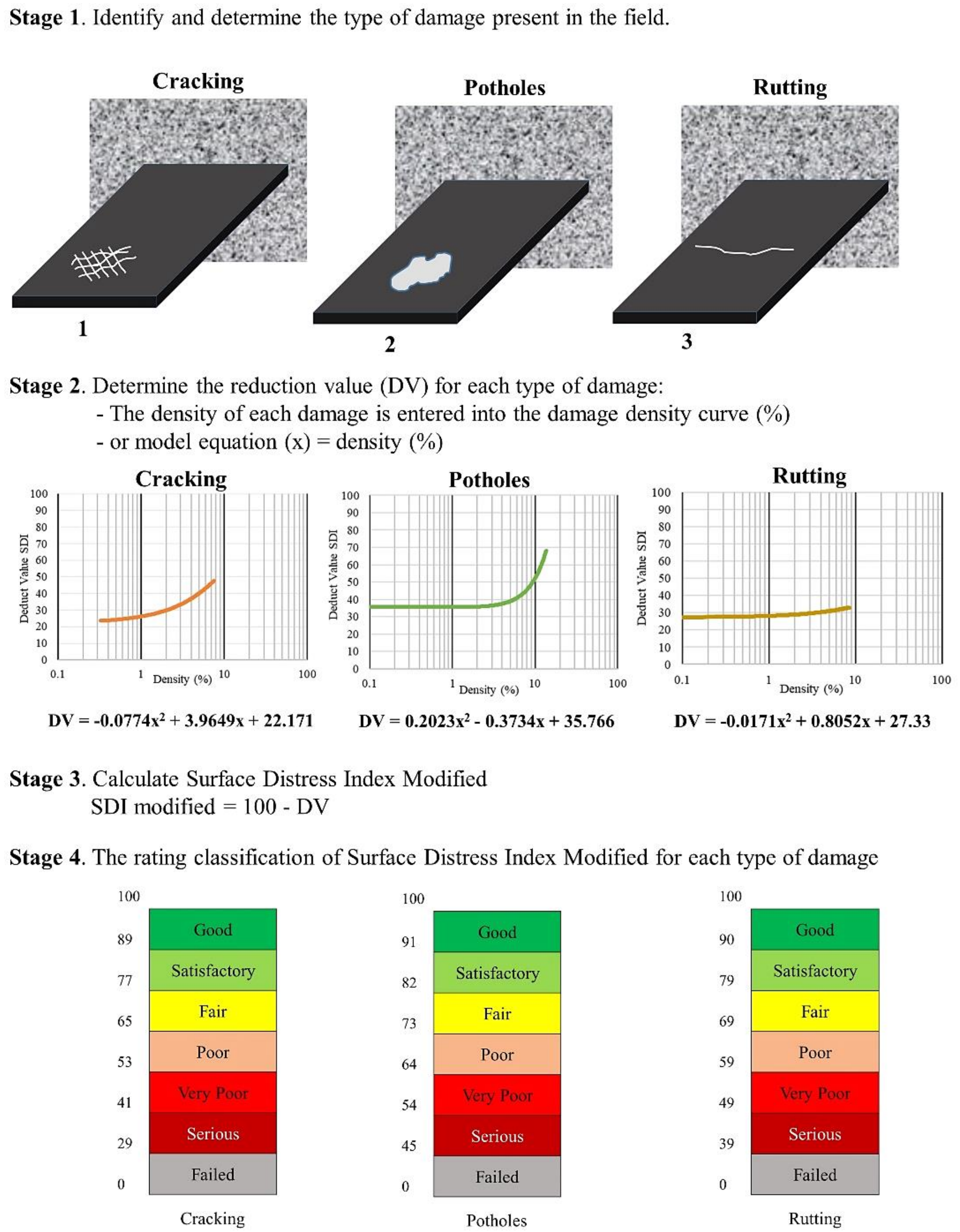



**Figure 11. The proposed of SDI Modified**

## 4. Conclusions

The study results indicate that the modified SDI can determine each type of damage individually instead of depending on cumulative previous estimates, as in the original SDI method. In addition, the development of each kind of damage (cracking, potholes, and rutting) generates several evaluation indicators, including customized DV curve models and specific damage equations, condition index, condition rating, and maintenance types.

In general, the modified SDI model improves the reliability and precision of pavement evaluation approaches. However, previous approaches, particularly the original SDI and PCI implementations, lacked precision and were challenging to execute in the field. The regional road sections observed had a higher SDI-modified value index range than the original PCI rating. Therefore, regional road sections in Indonesia with a higher condition index would not require maintenance, and lower index sections would need to be prioritized for maintenance.

The model developed for each type of damage generates a different assessment rating based on the type of damage present on the flexible pavement. However, in this study, only three types of damage were used to develop the model. Prospects for further research suggest all three sorts of damage in an area of pavement could be combined in a DV curve model by developing a new DV correction factor associated with a new DV curve. Future research is to be able to separate and combine the three types of damage in a DV model by developing a modified DV curve correction factor.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, F.G., B.S.S., R.B.F., and S.S.W.; methodology, F.G., B.S.S., R.B.F., and S.S.W.; validation, F.G. and R.B.F.; formal analysis, F.G.; investigation, F.G.; resources, F.G.; data curation, F.G. and B.S.S.; writing—original draft preparation, F.G.; writing—review and editing, F.G., B.S.S., R.B.F., and S.S.W.; visualization, F.G.; supervision, B.S.S., R.B.F., and S.S.W.; project administration, F.G.; funding acquisition, F.G. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in the article.

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### 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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