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Improvement of Potholes and Rutting Assessment in Surface Distress Index*

Bagus Hario Setiadji
Department of Civil Engineering
Diponegoro University
Semarang, Indonesia
bhsetiadji@ft.undip.ac.id

Djoko Purwanto
Department of Civil Engineering
Diponegoro University
Semarang, Indonesia
djokopurwt@gmail.com

Y I Wicaksono
Department of Civil Engineering
Diponegoro University
Semarang, Indonesia
ikho_w@yahoo.com

***Abstract*—To monitor and evaluate the functional condition of roads, an easy-to-understand and powerful parameter is important for countries whose road regulators have different capabilities, such as Indonesia. To date, Surface Distress Index (SDI) is still the most popular parameter for assessing the road functional condition in Indonesia, due to its simplicity and easy-to-understand features. However, the index has a lack of accurateness in assessing the damages. In this study, an improvement of the effectiveness of the damage assessment equation in SDI, especially for pothole and rutting damages, was carried out to increase the accuracy of the SDI in evaluating the functional conditions of the road. For this purpose, the damage assessment equations in the proposed SDI were developed based on the deduct values from Pavement Condition Index (PCI) that adjusted to the maximum value of the damage contribution for both types of distress. This study produces findings that the equations developed could produce more sensitive and consistent SDI values at different distress densities and levels of severity than that of the existing one.**

Keywords: functional condition, Surface Distress Index, potholes, rutting

I. INTRODUCTION

Evaluation of road functional condition is one type of evaluation that has to be carried out routinely to ensure it is always in good condition. Especially for evaluating flexible pavement condition based on damage data, at present, there are several single-index used to reflect the overall road surface conditions based on the accumulation of road damage occurred, such as Pavement Condition Index (PCI) [1, 2], Surface Distress Index (SDI) [3], and Road Condition Index (RCI) [4].

Of the three indices, SDI is the most popular index and is used at different levels of the highway authority. SDI is more preferable because it only evaluates three main road damages, that is, cracking, potholes and rutting, making it easier for surveyors in the field to carry out data collection. However, the simplicity of SDI also has drawback, such as, the lack of detail in the properties of the distresses, where SDI only consists of the density and severity level of one type of cracking, the number of potholes without any differences in density and severity level of potholes, and the average depth of rutting.

On the other hand, PCI is recognized by AASHTO [5] as the most comprehensive functional condition index in the world due to it covers 19 types of road damage, and this makes the index can accurately evaluate road pavement condition. However, with so many types of distress that have to be identified, this causes the measurement process to become too complex and requires experienced people in the field, making it difficult to be implemented especially for a low-level highway authority.

To overcome this, Setiadji et al. [6] have conducted preliminary research to empower SDI, instead of PCI, by increasing the ability of SDI in assessing crack damage. The accuracy of SDI in assessing the distress was improved by adding crack damage assessment equations, from only one equation in the existing SDI becomes 7 equations in the proposed SDI. This improvement made SDI could better recognize different crack damages, and be able to minimize the errors in crack damage recognition by a maximum of 6.25%.

Based on Setiadji et al. [6], the improvement of the proposed SDI was continued in this study by increasing the accuracy of damage assessment of two other distresses in SDI, i.e. potholes and rutting. Therefore, this study aims to develop new potholes and rutting damage assessment equations in SDI to improve the accuracy of SDI in evaluating road functional condition.

II. INDICES OF ROAD FUNCTIONAL CONDITION

In this section, the two most popular indices used in Indonesia, SDI and PCI, that elaborating the two distresses, i.e. potholes and rutting, are presented.

A. Surface Distress Index (SDI)

SDI is an index of road functional condition which use is regulated in the Road Condition Survey Guide. [3]. SDI only consists of three types of road distress, namely cracking, potholes and rutting. These three types of distress contribute differently to SDI, depending on the ratio of damage area to the area being evaluated (or called as density). The index represents a cumulative contribution of damage caused by the three types of distress for distance 100 m long. For potholes and rutting, the damage assessment equations are as follows.

a) SDI_3 as a function of total area and average width of crack (SDI_2)

$SDI_3 = SDI_2$, if there are no potholes (1)

$SDI_3 = SDI_2 + 15$, if the total number of potholes is less than 10 per km

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$SDI_3 = SDI_2 + 75$, if the total number of potholes is in between 10 and 50 per km

$SDI_3 = SDI_2 + 225$, if the total number of potholes is more than 50 per km

b) SDI_4 as a function of the total number of potholes (SDI_3)

$SDI_4 = SDI_3$, if there is no rutting (2)

$SDI_4 = SDI_3 + 2.5$, if the average depth of rutting is less than 1 cm

$SDI_4 = SDI_3 + 10$, if the average depth of rutting is in between 1 and 3 cm

$SDI_4 = SDI_3 + 20$, if the average depth of rutting is more than 3 cm

For potholes, there is no clear explanation regarding pothole dimension and depth. Besides, the damage assessment is determined based on the number of potholes only and there is an inconsistency in the length of area evaluated, that is, 100 m long as stated in the procedure of the Guide [3] and 1000 m (1 km) long as used in the unit of the damage assessment. This makes a problem in how to synchronize between the measurement and the assessment results and leads to errors in the result obtained. While for rutting, it is only mentioned about the severity level of the distress and not the distress density.

Regardless of SDI values from the previous calculation (SDI_1 and SDI_2) [6], the maximum values of SDI_3 and SDI_4 are 225 and 20, respectively for pothole and rutting damage. The comparison of both maximum values of SDI indicates that SDI of pothole damage (SDI_3) has a very significant contribution of damage than that of the rutting damage. The contribution of damage of potholes is also larger (as much as three times) than that of the cracking one [6].

B. Pavement Condition Index (PCI)

PCI is also an index that shows the functional condition of a road surface where the smaller PCI value indicates that the road has the worse condition. The maximum value of PCI is 100, while the number of distresses covered in PCI is 19 types of distress. Each type of distress can be a deduct value for PCI. The deduct value of each distress is based on several factors such as density and level of severity.

For pothole damage, the deduct value is determined first by the diameter of the pothole. If the average diameter of the pothole is less than 750 mm, the determination of the level of severity is as shown in TABLE I.

TABLE I. LEVEL OF SEVERITY OF POTHOLES [1, 2]

Maximum pothole depth (mm)	Average diameter (mm)		
	100 – 200	200 – 450	450 – 750
13 – 25	Low	Low	Medium
25 – 50	Low	Medium	High
> 50	Medium	Medium	High

If the average diameter of the pothole is more than 750 mm (30 in.), then the area of the pothole has to be divided by 0.5 m2 (5.5 ft^2) and then expressed the result as the equivalent number of potholes. Regarding the level of severity, pothole which has a maximum depth of 25 mm is stated as medium-severity, and high-severity if the maximum depth of the pothole is the opposite.

For rutting damage, the level of severity of the rutting is expressed as a function of its depth, as follows.

a) low (L) severity: if the mean rut depth is between 6 and 13 mm.

b) medium (M) severity: if the mean rut depth is between 13 and 25 mm

c) high (H) severity: if the mean rut depth is in more than 25 mm

III. RESEARCH METHODOLOGY

This study consisted of several main steps as follows.

a) Developing Pothole and Rutting Damage Assessment Equations in SDI

In this study, the pothole damage assessment equation in the proposed SDI used two properties of pothole damage from PCI, namely the diameter and the depth of pothole, to improve the accuracy of identifying the level of severity of pothole damage, instead of only considering number of potholes as in the existing SDI. Using the two pothole properties, the level of severity of the pothole damage, i.e. low, medium and high, can be determined by following the procedure as described in the previous section. This level of severity, together with the density of the pothole damage, then is used to determine the deduct value using the charts in Figs. 1 and 2.

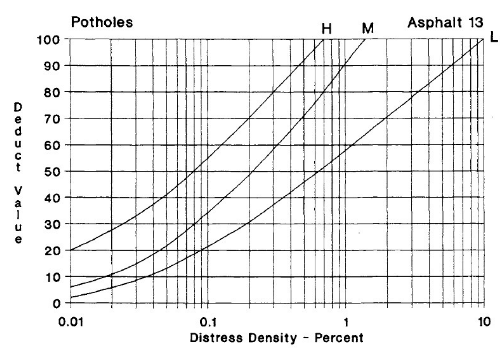

Fig. 1. Deduct value charts for potholes [1, 2]

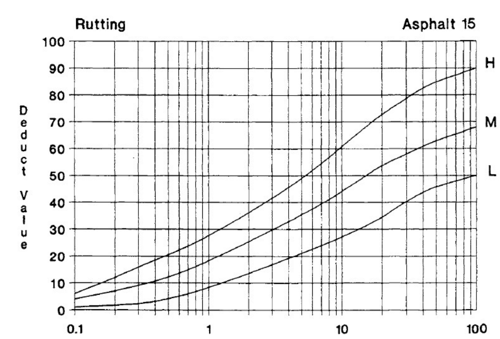

Fig. 2. Deduct value charts for rutting [1, 2]

For rutting damage, the determination of the level of severity (low/L, medium/M, and high/H) can still use the definition of level of severity in the existing SDI, because the range of mean rut depth for the three levels of severity between SDI and PCI does not differ significantly.

To be able to provide continuous deduct values, the density values used were all possible values from the charts in Fig. 1, i.e. pothole damage between 0.01% and 10% (which varies between the level of severity), and rutting damage between 0.1 % and 100% (for all severities).

The deduct value obtained then was adjusted based on the maximum contribution of damage in the existing SDI, that is, 225 and 20, respectively for pothole and rutting damages, and stated as the proposed SDI for pothole and rutting damages. Using the relationship between the proposed SDI and its corresponding distress and level of severity, the damage assessment equations were derived. These proposed SDI then were used in the cumulative calculation of SDI, together with the proposed SDI of crack damage that has been developed previously [6]. The proposed SDI for pothole and rutting damage.

b) Conducting a Statistical Test to Ensure the Correctness of the Proposed Equations

Statistical testing, in the form of a two-tailed t-test, was conducted in this study to provide evidence of the hypothesis that the SDI values for each level of severity obtained in the previous step could show different results.

c) Conducting validation of the equations using hypothetical data

This validation process is important to ensure that the equation used meets the requirements with the resulting values, one of which is related to the sensitivity of the results. The use of hypothetical data makes it possible to maximize the use of all possible data in the developed equation.

IV. RESULTS AND ANALYSIS

The first step of this study was the development of pothole and rutting damage assessment equations in the proposed SDI based on the deduct value charts from PCI (Fig 1). The deduct value obtained, which is a function of distress density and level of severity, was then converted to SDI by adjusting the deduct value to the maximum contribution of damage using the following equation:

$$SDI_i = SDI_{i\text{-}max} * DV_j / DV_{i\text{-}max} \quad (3)$$

in which:

SDI_i = SDI values for each distress, i = potholes, rutting

$SDI_{i\text{-}max}$ = maximum contribution of damage for distress i (as stated in Road Condition Survey Guide [3])

DV_j = deduct value for density j, j = 1 – 100%

$DV_{i\text{-}max}$ = deduct value at the highest severely damage level of stress i

The damage assessment equations in the proposed SDI for all densities are shown in TABLE II and TABLE III, respectively for pothole and rutting damage. The equations obtained generally: (i) have a high order (three or more); (ii) in the form of either a linear, polynomial or logarithmic; (iii) consist of two ranges of density values, to enable modeling SDI better; and (iv) have the coefficient of determination (R2) greater than 0.9.

TABLE II. THE POTHOLE DAMAGE ASSESSMENT EQUATION IN THE PROPOSED SDI

Level of severity	SDI equation on different density values	SDI equation on different density values
	0 < density < 1	Density ≥ 1
Low	$y = -597.58x^4 + 1450x^3 - 1269.8x^2 + 541.98x + 4.3501$	$y = 0.1557x^3 - 3.6165x^2 + 32.887x + 103.08$
Medium	$y = -963.58x^4 + 2316.8x^3 - 1992x^2 + 828.62x + 10.622$	$y = 45x + 157.5$
High	$y = -46628x^6 + 105282x^5 - 93121x^4 + 41494x^3 - 10221x^2 + 1596x + 32.788$	

TABLE III. THE RUTTING DAMAGE ASSESSMENT EQUATIONS IN THE PROPOSED SDI

Level of severity	SDI equation on different density values	SDI equation on different density values
	0 < density < 1	Density ≥ 1
Low	y = 0.0141x3 - 0.2835x2 + 2.1052x + 0.0118	y = 2.0313ln(x) + 1.8323
Medium	y = -0.0044x4 + 0.107x3 - 0.941x2 + 3.9627x + 0.876	y = -3E-07x4 + 8E-05x3 - 0.0079x2 + 0.378x + 6.7981
High	y = -0.0073x4 + 0.1728x3 - 1.4453x2 + 5.5948x + 1.7596	y = 2E-05x3 - 0.0044x2 + 0.3299x + 10.807

To ensure that all equations in TABLE II and TABLE III represent the appropriate level of severity and to check the possibility of the equation from a different level of severity overlap each other, it is necessary to do a two-tailed t-test with a 95% confidence level. The results of this statistical test are presented in TABLE IV. The hypothesis used was whether the damage assessment equation of one level of severity is similar to that of another level of severity. From the results of the statistical tests in TABLE IV, it appears that there is no similarity between the damage assessment equations with different levels of severity. This shows that the damage assessment equations in the proposed SDI were appropriate for all density values and levels of severity.

TABLE IV. RESULTS OF TWO-TAILED T-TEST ON THE SIMILARITY OF POTHOLE AND RUTTING DAMAGE ASSESSMENT EQUATIONS AT DIFFERENT LEVELS OF SEVERITY

No.	Test hypothesis	Results	
1	The rutting damage assessment equations at low and moderate severities are similar	t_0	14,281
		$t_{0.05, n-1}$	2,052
		Conclusion	Rejected
2	The rutting damage assessment equations at medium and high severities are similar	t_0	12,074
		$t_{0.05, n-1}$	2,052
		Conclusion	Rejected
3	The pothole damage assessment equations at low and moderate severities are similar	t_0	8,252
		$t_{0.05, n-1}$	1,701
		Conclusion	Rejected
4	The pothole damage assessment equations at medium and high severities are similar	t_0	7,016
		$t_{0.05, n-1}$	1,701
		Conclusion	Rejected

The next step was to check the validity of the proposed SDI equation for all possible density values. For this purpose, hypothetical data was used in this study. To test the validity of the equations, several damage samples are taken for both types of damage, as shown in TABLE V and TABLE VI. TABLE V uses two hypothetical data, i.e. diameter and depth of potholes, to define the level of severity of pothole damage, while TABLE VI also uses two hypothetical data, i.e. length and mean depth of the rutting.

TABLE V shows that the existing SDI is only determined by the number of potholes, and is not affected by the density. In contrast, the proposed SDI is greatly affected by the density, which is indirectly a function of the number of potholes. In TABLE VI, aside from the fact that the proposed SDI is dependent on the density and the level of severity, nothing significant is given by rutting damage to the accumulative proposed SDI. In both tables, it can be found that there is a proposed SDI value that exceeds the maximum contribution of damage so that the final value proposed is the maximum value, i.e. 225 and 20 for the potholes and rutting damages, respectively.

Finally, from TABLE V and TABLE VI, it can be summarized that: (i) in general, the existing SDI underestimates the proposed SDI; and (ii) the proposed SDI is more sensitive towards the changes in the level of severity and density than that of the existing SDI.

TABLE V. EXAMPLES OF THE DETERMINATION OF PROPOSED SDI VALUES FOR POTHOLE BASED ON HYPOTHETICAL DATA

No	Level of severity (LoS)	Diameter (m)	Depth (cm)	No. of potholes per LoS / density (%)	Existing SDI value	Proposed SDI value per LoS	Total proposed SDI value	Recommended proposed SDI value
S1-1	Low	0.280	1.5	Low = 4/ 0.667	225	Low = 112.928	252.29	225.00[a]
	Low	0.449	1.5					
	Low	0.282	1.3					
	Low	0.163	1.3					
	Medium	0.511	1.3	Medium = 2/0.333		Medium = 139.363		
	Medium	0.568	2.0					
S1-2	Medium	0.638	1.3	Medium = 1 / 0.167	15	Medium = 65.736	65.74	65.74
S1-3	Low	0.314	1.3	Low = 2 / 0.333	75	Low = 90.217	90.22	90.22
	Low	0.249	1.3					
S1-4	Low	0.429	2	Low = 3 / 0.500	75	Low = 101.791	205.28	205.28
	Low	0.256	1.3					
	Low	0.116	1.3					
	Medium	0.721	1.5	Medium = 1 / 0.167		Medium = 103.488		
S1-5	Low	0.162	2.7	Low = 3 / 0.500	75	Low = 101.791	199.96	199.96
	Low	0.088	1.3					
	Low	0.233	1.3					
	High	0.613	1.3	High = 1 / 0.152		High = 98.171		

a. Highest SDI value for potholes

TABLE VI. EXAMPLES OF THE DETERMINATION OF PROPOSED SDI VALUES FOR RUTTING BASED ON HYPOTHETICAL DATA

No	Level of severity (LoS)	Length (m)	Depth (cm)	Average depth (cm)	Density (%)	Existing SDI value	Proposed SDI value per rutting distress	Total proposed SDI value	Recommended proposed SDI value
S2-1	Medium	5.000	2.0	1.7	0.758	10	3.383	11.22	11.22
	Medium	5.000	1.5		0.758		3.383		
	Medium	5.556	2.0		0.842		3.606		
	Low	2.778	1.3		0.421		0.849		
S2-2	Medium	13.175	2.1	2.2	2.196	10	6.071	16.54	16.54
	High	6.550	3.0		1.092		6.359		
	Medium	6.275	1.4		1.046		4.108		
S2-3	Low	0.263	0.7	0.7	0.040	2.5	0.095	0.41	0.41
	Low	0.983	0.7		0.149		0.319		
S2-4	Low	1.790	0.7	1.088	0.256	10	0.532	23.28	20[a]
	Low	18.831	1.3		2.690		3.898		
	Low	9.500	0.7		1.357		2.382		
	Medium	7.384	2.0		1.055		4.129		
	Medium	9.272	1.3		1.325		4.709		
	Low	4.500	0.7		0.643		1.252		
	Medium	8.545	1.3		1.221		4.496		

a. highest SDI value for rutting

V. CONCLUSIONS

This paper proposed an improved procedure to determine surface distress index (SDI) for pothole and rutting damage with different levels of severity and density. The research resulted in: (i) the damage assessment equations in the proposed SDI for pothole and rutting damages, with improved procedures in identifying the density and level of severity of potholes; (ii) the findings that the equations could produce more sensitive and consistent SDI values at different distress densities and levels of severity than that of the existing one.

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