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Development of Pavement Condition Index for Korean Asphalt National Highway and Decision Criteria for Resurfacing

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Abstract: This paper developed a model equation to represent various pavement distresses such as crack, rutting, roughness (IRI), etc. as one combined index in order to manage the pavement of Korean asphalt national highway system at network level. Additionally, the threshold values for rut depth and crack percent for resurfacing were determined to follow the recommendation of pavement evaluation panel experts. The research method for the development of NHPCI (National Highways Pavement Condition Index) involved selection of the sample size and research subject area of pavement. Then, an automated road analyzer for the investigation of pavement condition was used to measure the pavement condition quantitatively. Afterwards, ten panel experts qualitatively evaluated the measurement for a multiple regression analysis. Moreover, the threshold value for pavement resurfacing was set at 50% of the value recommended by the panel based on the rehabilitation strategies required by the pavement evaluation card and the result of influential factors for the selection of the rehabilitation strategy. The study resulted in R^2 value of 0.78 for the NHPCI model equation developed in this study, and sensitivity analysis revealed that roughness (IRI) and crack percent were sensitive. Finally, this study recommends average rut depth value of 11*mm*, crack percent of 20% as the threshold values for pavement resurfacing (overlay), and average rut depth value of 12*mm* as the threshold value for pavement mill-resurfacing (inlay).

***Key words**: Box-Cox transformation; Pavement condition index; Resurfacing; Sensitivity analysis; Threshold value.*

Introduction

The road network of Korea connects all major cities of Korea through express highway and national highway. Among the road network, the national highway system stretches to a total length of 15,861*km* as of 2008 and accounts for 15% of all national roads.

The asphalt national highway pavements have been managed by a PMS (Pavement Manage System) since 1987. Basically the original form of PMS was more like project level oriented. Pavement distresses such as rutting, cracking, and roughness were measured and the rehabilitation strategies were selected based on the severity and extent of each distress manifestation. Especially, since cracking among various kinds of pavement distress was evaluated by the crack percentage (%) over entire area regardless of the types of cracking at the network level PMS, a detailed inspection of PMS at project level was required for the decision to perform final rehabilitation and maintenance method.

It has been continually pointed out, however, that there should be some improvement in terms of network level. Higher level highway managers want to know the general pavement condition each year primarily for the budget planning purposes, priority of the comprehensive road maintenance, and selection of the rough rehabilitation strategies. Therefore a combined type index, such as Present Serviceability Index (PSI) or Maintenance Control Index (MCI), is needed. The combined index should reflect current Korean pavement conditions and interests of highway managers.

In Korea, rutting was the major distress up until 10 years ago, but these days, cracks and roughness are the major distresses that highway managers need to fight against. Therefore, it is needed to develop an appropriate combined type pavement condition index reflecting these situations.

In addition, it has also been pointed out that the objective basis for threshold value of distresses for decision of resurfacing is necessary as well.

Thus, this study aims at developing a combined index to represent various pavement distresses such as crack, rut depth, roughness (IRI), etc. for the management of the asphalt pavement at network level. Additionally, the threshold value for rut depth and the amount of crack is determined for possible pavement mill-resurfacing (inlay) and resurfacing (overlay) application. Of all rehabilitation methods, resurfacing strategies were considered within the scope of this research.

The development of NHPCI (National Highway Pavement Condition Index) was conducted by selecting 40 locations of representative national highway for the investigation of this study and then by performing a multiple regression analysis of the relationship between the pavement evaluation scores by ten pavement evaluation panel members and the pavement condition values recorded by an automated road analyzer. The multiple regression analysis used Pearson correlation coefficient and stepwise regression approach to select the independent variables and selected the model equation which yielded the least square value of the residuals of the regression model through Box-Cox

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transformation equation. The pavement condition values of 22,000 locations as measured by an automated road analyzer in the year of 2007 were used for the validity test and sensitivity analysis of the model equation. The limit value of rut depth and crack percent for the determination of the pavement rehabilitation strategy was determined to be the value, which over 50% of the panel evaluation members recommended in their evaluation of pavement condition rating card (required rehabilitation strategy and critical factors for the decision of rehabilitation strategy) used for the development of NHPCI previously.

Typical Pavement Condition Index

Present Serviceability Index (PSI)

The road test of AASHO began to use an objective index, PSI [1], for the service level of pavement. The panel group consisting of road construction engineer, road maintenance worker, automobile transporter, and automobile manufacturer, etc. evaluated the serviceability of pavement with the score range of 0-5 after actual driving on the road pavement. Eq. (1) indicates the result of the multiple regression analysis of the evaluation scores on the distresses of the asphalt pavement.

$$PSI=5.03-1.9\log(1+SV)-0.01\sqrt{C+P}*RD^2 \tag{1}$$

where,

SV : The dispersion of longitudinal profile at the location of the vehicle traffic,

RD : The depth of rutting (*cm*)

C : The degree of crack at the road surface ($m^2/1000m^2$),

P : The degree of patching at the road surface ($m^2/1000m^2$).

Maintenance Control Index (MCI)

MCI was developed by the Ministry of Construction of Japan in reference to PSI of America. They investigated the performance and condition of the road surface as well as the maintenance cost and road pavement rehabilitation strategy after new construction and pavement resurfacing for three years since 1979 in order to establish MCI. While PSI of America quantified the cruise comfort mainly from the perspective of the road users, MCI [2] quantified the well-being or deterioration of the road from the perspective of the road pavement managers. They inspected the road surface visually by following the standards and computed the overall average value.

MCI quantified and evaluated the influence of such characteristics of the road surface as rutting and crack on the road performance on a ten-point rating system. The result of the multiple regression of the data from 1,808 locations on asphalt pavement distresses is shown in Eq.n (2). The minimum MCI is selected as the MCI for that pavement.

$$MCI = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2} \tag{2}$$

$$MCI0 = 10 - 1.51C^{0.3} - 0.3D^{0.7}$$

$$MCI1 = 10 - 2.23C^{0.3}$$

$$MCI2 = 10 - 0.54D^{0.7}$$

where,

MCI : Maintenance Condition Index

C : Percentage of Crack (%)

D : Average rut depth (*mm*)

σ : Standard deviation of longitudinal profile (*mm*)

Pavement Quality Index (PQI)

An example of recent development of pavement condition index is Pavement Quality Index (PQI) developed in the State of Ohio [3]. PQI incorporates aspects of ride quality together with surface distress. The PQI is a combination of the International Roughness Index (IRI) and the previously used PCR (Pavement Condition Rating) which represents only surface distresses. The development of the new index is the reflection of the growing trend of increased emphasis on the road user satisfaction. The basic form of PQI is as follows:

$PQI = PCR - a\times IRI^b$

where,

PQI : Pavement Quality Index

PCR : Pavement Condition Index (Based on surface distress)

IRI : International Roughness Index

a and b : Constant

Development Procedure for NHPCI

The overall flowchart for the development of pavement condition index for Korean national highway is shown in Fig. 1.

First, national highway sections of various pavement conditions by distress factors are investigated preliminarily by the traffic volume in order to obtain the sample size adequate for statistical reliability, and then the investigation sections for the evaluation of the pavement condition are selected.

Second, the ratings of pavement evaluation panel members, which are used as the dependent variable of the model equation, are evaluated for all those road sections selected for the investigation of this study. Then, pavement distresses such as cracking, rutting, IRI (roughness), and so on, which are used as independent variables of the model equation, are measured by automated road analyzer.

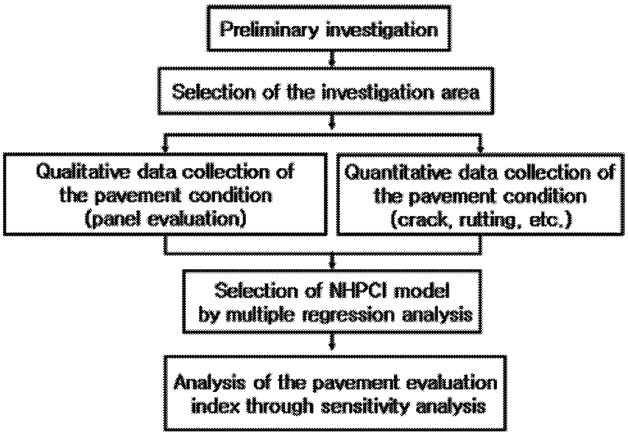


Fig. 1. Flowchart for the Development of NHPCI (National Highways Pavement Condition Index).

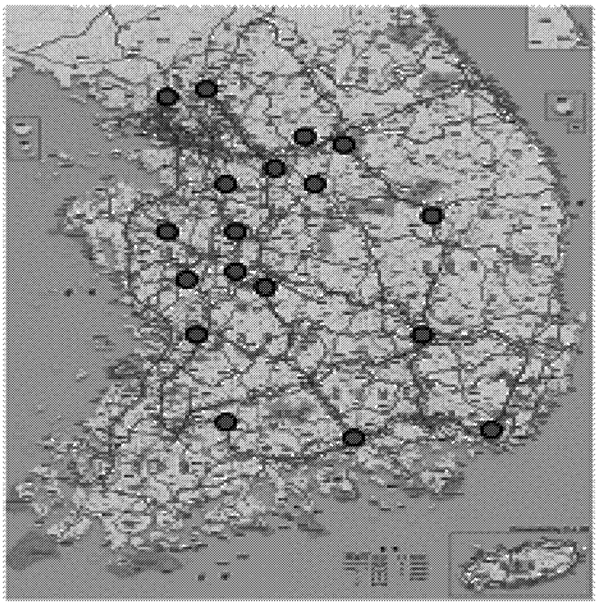


Fig. 2. Investigation Sections.

Table 1. The Preliminary Selection of Investigation Sections (Investigation Section Number).

Classification	Rut Depth			Crack Percent			Patching Percent		
Traffic volume	H	M	L	H	M	L	H	M	L
H	1	2	0	2	2	2	1	1	1
M	3	2	2	2	2	2	0	0	0
L	2	2	2	2	2	2	1	1	1

Table 2. The Selection of the Sample Size for Each Pavement Distress.

Classification	Rut Depth	Crack Percent	Patching Percent
Allowed Error Range	0.5*mm*	2%	2%
Sample Size	16	18	6
Average	8.97	10.84	5.79
Standard Deviation	5.02	15.88	15.87
Probability within the Allowed Error	66%	70%	61%

Table 3. Classification of the Severity (Severe, Average, Modest) of the Deterioration by the Distress Type and Traffic Volume.

Severity of Deterioration	Traffic Volume (ESALs/day)	Rut Depth (*mm*)	Crack Percent (%)	Patching Percent (%)
Severe	over 3,000	over 20	over 25	over 60
Average	1,000~3,000	10~20	5~25	30~60
Modest	0~1,000	0~10	0~5	0~30

ESALs: Equivalent Single Axle Loads

Third, the relationship between the data measured by automated pavement condition analyzer and the ratings of pavement evaluation panel members is analyzed by multiple regression analysis. Especially, those independent variables of the model equation, which can explain the pavement condition statistically well, are selected to include the important pavement distress factors.

Finally, the developed model equation is tested for statistical hypothesis through line of equality analysis, and the influence of each independent variable on NHPCI is analyzed through a sensitivity analysis.

Selection of the Investigation Area

The national highway pavement sections of 200*m* length were selected from 40 locations throughout Korea in order to obtain statistically reliable samples, as shown in Fig. 2. The 40 locations to be surveyed were selected based upon the various pavement conditions and traffic volume as shown in Table 1. Note that pavement deterioration types such as rut depth, crack percent, and patching percent were selected to evaluate pavement conditions in Table 1. This is because of that these three pavement distresses have already known as a standard to conduct pavement rehabilitations according to the Ministry of Land, Transport, and Maritime Affairs of Korea.

The minimum sample size necessary for the development of the model equation was determined as shown in Table 2. The sample size of the Table 2 was computed from Eq. (3) by using the average and standard deviation of each defect obtained from a preliminary investigation so that the limit of error is to be within 10% for the development of the model equation.

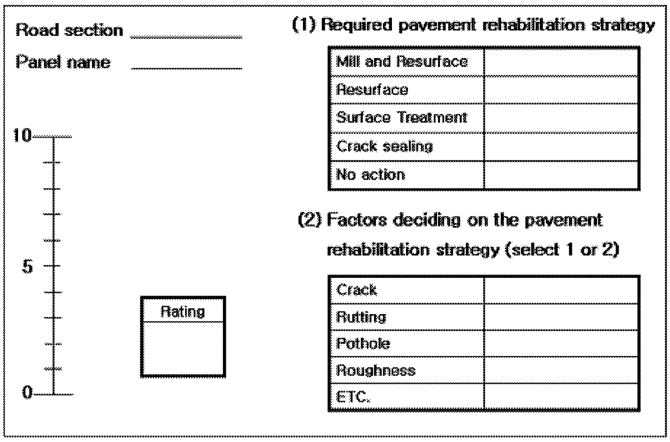
$$n \geq \left(\frac{z_{\alpha/2} \times \sigma}{d} \right)^2 \tag{3}$$

where,
n : Sample size,
$z_{\alpha/2}$: 100 × $z_{\alpha/2}$ the percentile of standard normal distribution,
σ : Standard deviation of the sample group,
d : Limit of error.

Additionally, the traffic volume and the severity of deterioration of those 40 selected pavement sections was classified into three categories as shown in Table 3 by the range and distribution of the investigation data.

Panel Rating

Ten pavement evaluation panel members from government, industry, academic institution, and research institute filled out the pavement



Road section __________

Panel name __________

(1) Required pavement rehabilitation strategy

Mill and Resurface	
Resurface	
Surface Treatment	
Crack sealing	
No action	

(2) Factors deciding on the pavement rehabilitation strategy (select 1 or 2)

Crack	
Rutting	
Pothole	
Roughness	
ETC.	

Fig. 3. Pavement Evaluation Card.

Table 4. Average of Pavement Evaluation Panel Members' Ratings by Each Pavement Evaluation Section.

Pavement Evaluation Section Number	9A	12	12A	14	15A	6	21	1	2	2A	20	8	8A	16
Average of Panel Ratings	5.57	4.49	6.01	5.73	5.06	4.49	3.91	5.03	5.97	6.49	5.12	4.72	4.96	7.40

Pavement Evaluation Section Number	25	24	24A	11	10A	5	5A	26A	26	19A	18	17	17A	31A
Average of Panel Ratings	6.87	7.50	6.76	4.10	4.03	4.65	2.48	7.29	7.98	5.92	5.40	6.21	6.04	6.46

Pavement Evaluation Section Number	32	31	23	30	29	28	3	4	4A	3A	27	19
Average of Panel Ratings	6.85	6.23	4.86	5.68	5.19	4.92	3.29	3.93	3.86	4.29	3.60	7.74

Fig. 4. Pavement Condition Rated by the Panel Experts.

Fig. 5. Automated Road Analyzer.

evaluation card as shown in Fig. 3 to evaluate and rate the pavement condition of investigation site. All the panel members were educated how to rate the pavement conditions at the beginning. There were discussions after several ratings in order to keep the consistency of the rating scale. After that, the pavement conditions were evaluated by each panel member's subjective judgment. The pavement condition was investigated by walking along the shoulder lane of each pavement section as seen in Fig. 4. Pavement condition was evaluated by visual inspection of each respective pavement section under the investigation and then was rated from 0 to 10 scale system. Zero score indicates the most severely damaged pavement condition, and ten represents perfect pavement condition without any deterioration. Additionally, the score of five (5.0) represents the pavement condition requiring resurfacing strategy after new pavement. The final panel rating was set to be the average of the ten panel ratings for each pavement section, and it is summarized in Table 4.

Additionally, the determination of required pavement rehabilitation strategy and factors deciding on the pavement rehabilitation strategy pursuant to the panel ratings of the pavement evaluation card (Fig. 3) was also used to discuss the last section titled "Determination of Criteria for Pavement Resurfacing" in this study.

Quantitative Performance Data Collection

An automated road analyzer was used to measure the quantitative value of the pavement condition at those 40 road sections, where the pavement evaluation panel rated the pavement condition. The ARAN (Automated Road ANalyzer) investigated the crack percent, rutting, roughness (IRI), patching, pothole, etc. as indication for the pavement condition of the 200*m* road section. The ARAN equipment featured in Fig. 5 uses a laser system to measure the rutting and roughness of the road surface and derives the crack percent, area and number of patching, and pothole through a video image analysis captured while cruising over the pavement. The result of the pavement condition measurement by the ARAN on those 40 locations of investigation is shown in Table 5.

Development of NHPCI

Selection of Independent Variables

SAS statistical program package was used to select the independent variables for the development of the NHPCI model equation. The independent variables are selected on the basis of Pearson correlation coefficient to possess a satisfactory explanatory power for the dependent variable. For the case in which the independent variables are highly correlated and yet have a weak explanatory power, they were not further considered in the development of the model. The Pearson correlation coefficients of Table 6 represent the correlation coefficient between each variable and the P-value for the correlation. Correlation coefficient is a value indicating the degree of correlation between each variable, and P-value indicates the correlation coefficient in consideration of the sample size. The result of this Pearson correlation coefficient analysis indicates that the dependent variable, i.e. the rating of panel members, had a significant P-value of greater than 95% confidence level of rejecting the null hypothesis (which means no correlation) with such independent variables as crack, rut depth, and roughness. Additionally,

Table 5. Pavement Surface Distresses and Roughness (IRI) Values as Measured by an Automated Road Analyzer.

Crack (%)	Rut Depth (*mm*)	Roughness, IRI (*m/km*)	Number of Patching	Patching (m^2)	Patching Rate (%)	Number of Pothole	Pothole (m^2)
10.84	6.55	2.15	0.00	0.00	0.00	0.00	0.00
2.31	18.50	3.25	0.00	0.00	0.00	0.00	0.00
0.56	12.70	3.07	0.00	0.00	0.00	0.00	0.00
11.67	5.50	1.95	0.00	0.00	0.00	0.00	0.00
16.30	10.05	1.80	0.00	0.00	0.00	3.00	3.00
12.75	3.45	1.41	0.00	0.00	0.00	0.00	0.00
0.17	15.35	2.85	1.00	4.32	0.62	0.00	0.00
23.75	4.35	1.68	0.00	0.00	0.00	0.00	0.00
1.65	5.65	2.18	0.00	0.00	0.00	0.00	0.00
2.44	6.75	2.38	0.00	0.00	0.00	0.00	0.00
2.98	16.43	2.48	2.00	20.16	2.88	0.00	0.00
1.49	6.15	3.03	0.00	0.00	0.00	1.00	0.36
2.83	9.35	2.51	0.00	0.00	0.00	0.00	0.00
0.90	10.95	1.93	0.00	0.00	0.00	0.00	0.00
9.21	4.10	1.61	0.00	0.00	0.00	0.00	0.00
0.08	8.45	3.35	0.00	0.00	0.00	0.00	0.00
1.35	7.84	2.64	0.00	0.00	0.00	0.00	0.00
0.01	25.03	3.57	0.00	0.00	0.00	0.00	0.00
34.28	4.40	1.82	0.00	0.00	0.00	0.00	0.00
26.69	7.60	3.78	0.00	0.00	0.00	0.00	0.00
64.90	6.30	3.72	0.00	0.00	0.00	0.00	0.00
4.14	4.40	1.97	0.00	0.00	0.00	0.00	0.00
2.34	3.80	1.97	0.00	0.00	0.00	0.00	0.00
0.26	13.30	1.88	0.00	0.00	0.00	0.00	0.00
3.60	11.55	2.37	0.00	0.00	0.00	0.00	0.00
0.99	7.80	1.89	0.00	0.00	0.00	0.00	0.00
4.76	7.5	2.01	0.00	0.00	0.00	0.00	0.00
2.38	6.10	1.86	7.00	103.23	14.75	1.00	0.36
0.01	4.65	1.92	3.00	466.47	66.64	1.00	0.54
0.41	5.70	3.60	4.00	363.96	51.99	10.00	3.24
0.08	15.70	2.87	0.00	0.00	0.00	0.00	0.00
0.13	4.60	2.76	3.00	58.90	8.41	0.00	0.00
6.52	4.70	3.06	4.00	305.82	43.69	1.00	0.18
10.89	5.00	3.57	5.00	298.71	42.67	0.00	0.00
29.03	14.75	3.66	0.00	0.00	0.00	0.00	0.00
37.77	6.40	2.91	0.00	0.00	0.00	0.00	0.00
22.31	11.60	3.01	0.00	0.00	0.00	0.00	0.00
20.33	11.60	3.01	0.00	0.00	0.00	0.00	0.00
60.61	6.35	2.42	0.00	0.00	0.00	0.00	0.00
0.01	10.50	1.76	0.00	0.00	0.00	0.00	0.00

Table 6. Pearson Correlation Coefficient (Correlation Coefficient, P-value).

	Panel Rating	Crack Percent	Rut Depth	Roughness	Number of Patching	Patching Percent	Area of Patching	Number of Potholes	Area of Pothole
Panel Rating	1.000	-0.1666 <0.0001	-0.6665 0.0455	-0.46935 0.0022	0.02398 0.8832	0.14804 0.3619	0.14804 0.3619	0.08161 0.6166	0.04233 0.7954

Table 7. Result of Stepwise Regression for Selection of Independent Variables.

Independent Variable	Significance	R-square	Remark
Crack	99%	0.44	
Crack and Rut Depth	99%	0.63	
Crack, Rut Depth, and Roughness(IRI)	92%	0.66	Selected
Crack, Rut Depth, Roughness(IRI), Patching Percent	33%	0.63	

a stepwise regression was performed to find out whether there is a need for removing additional dependent variables.

Stepwise regression is a method of selecting appropriate independent variables by including each variable stepwise. The result of the stepwise regression indicates that all those independent variables (crack percent, rut depth, and roughness (IRI)) were determined to be appropriate for the use of them as the independent variables of the model equation as shown in Table 7 with significance level of 92% and R-square value of 0.66. In addition, the patching percent correlation with the dependent variable was low.

Transformation of the Dependent Variable Using Box-Cox Transformation Equation

Although a model equation can be obtained from multiple regression analysis of the dependent variables selected by the stepwise regression, a model equation with higher statistical significance could be obtained by transforming the dependent variables through the analysis of the scatter plot of the dependent variables. Fig. 6 represents the scatter plot of the relationship between dependent variable (panel rating) and independent variables (selected from the stepwise regression - Crack percent, Rut depth, and Roughness). It can be seen that although the crack percent and rut depth decreases, the value of the dependent variable increases and the dispersion increases with the dependent variable. In order to solve this problem of scattering, Box-Cox transformation Eqs. (4) and (5) were used to replace the dependent variable (panel rating- represented by the symbol y) to minimize the sum of squared residuals [4].

$$y_i^{(\lambda)} = \frac{y_i^{\lambda}-1}{\lambda \times y_{gm}^{\lambda-1}} \ , \lambda \neq 0$$
$$= y_{gm} \times \log(y) \ , \ \lambda = 0 \qquad (4)$$

$$f(y,\lambda) = -\frac{n}{2}\log\sum_{i=1}^{n}\frac{1}{n}(y_i^{\lambda}-y_{gm}^{\lambda})^2 + (\lambda-1)\sum_{i=1}^{n}\log(y) \qquad (5)$$

Where,

y : Dependent variable of the model equation,

λ : Transformation variable of the dependent variable for the model equation,

n : Number of the pavement investigation section,

y_{gm} : Geometry average of the dependent variables ($= e^{\frac{1}{n}\sum_{i=1}^{n}\log(y_n)}$).

Here, Eq. (4) is the method to approximate non-normal distribution to normal distribution of dependent variable and Eq. (5) is the method for 40 road sections to find out the sum of squared residuals of dependent variables transformed by Eq. (4). As a result of SAS statistical program by using Eqs. (4) and (5), the minimum sum of squared residuals could be obtained when the dependent variable y is transformed to $y^{-0.5}$.

Thus, the final model developed can be expressed as follows,

$$NHPCI^{-0.5} = 0.33 + 0.003X_{crack} + 0.004X_{rutdepth} + 0.018X_{IRI} \qquad (6)$$

or,

$$NHPCI = \frac{1}{(0.33 + 0.003X_{Crack} + 0.004X_{Rutdepth} + 0.018X_{IRI})^2} \qquad (7)$$

where, $NHPCI$: National Highway Pavement Condition Index,

X_{crack} : Crack percent (%),

$X_{rutdepth}$: Rut depth (*mm*),

X_{IRI} : IRI (International Roughness Index, *m/km*).

The result of using Box-Cox transformation for the dependent variable improved the R-square (correlation) value from 0.66 to 0.78, and the P-value (the confidence level of the relationship between the dependent variable and independent variables) was enhanced from 92 to 98% level.

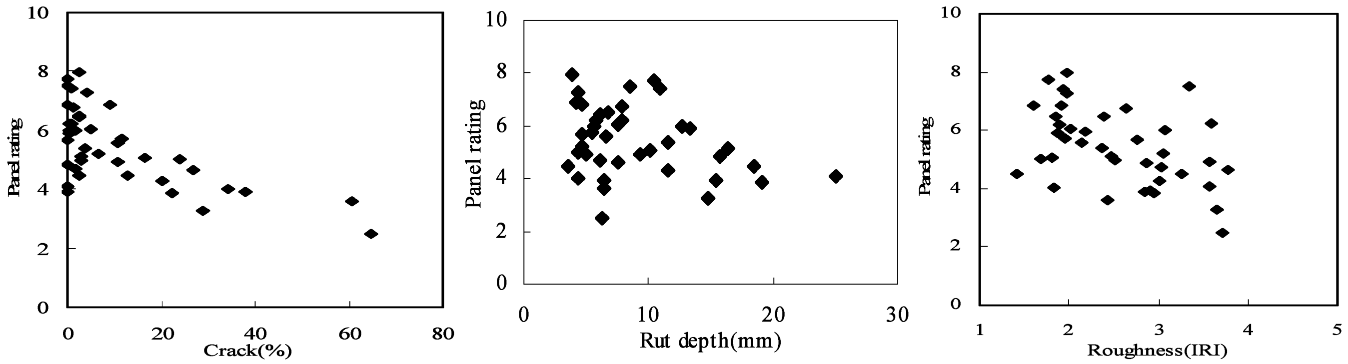


Fig. 6. Relationship between the Dependent Variable (Panel Rating) and Independent Variables (Crack Percent, Rut Depth, and Roughness).

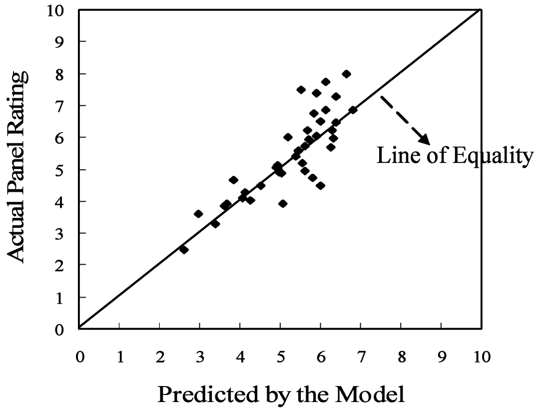


Fig. 7. Comparison between Predicted and Actual Value of NHPCI.

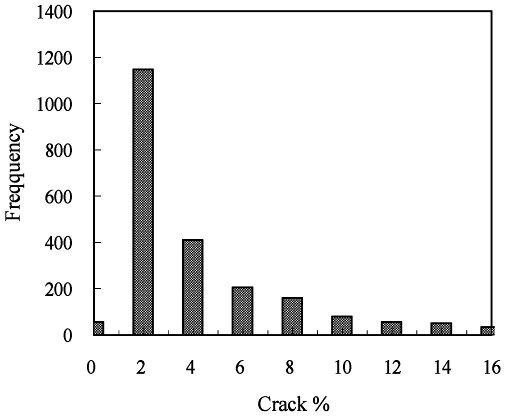


Fig. 8. Distribution of Severity Due to Crack Percent.

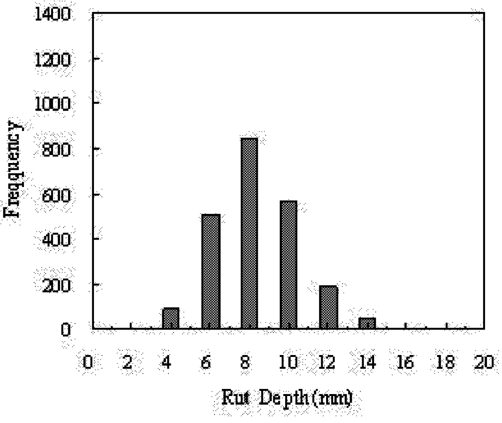


Fig. 9. Distribution of Severity Due to Rut Depth.

Comparison between the Predicted and Actual Value of NHPCI

The model equation for NHPCI developed in this study was tested for its validity by comparing the actual rating of panel members and the predicted value from the model equation. The relationship between the panel rating and predicted value from the model equation was investigated by the Line of Equality as shown in Fig. 7.

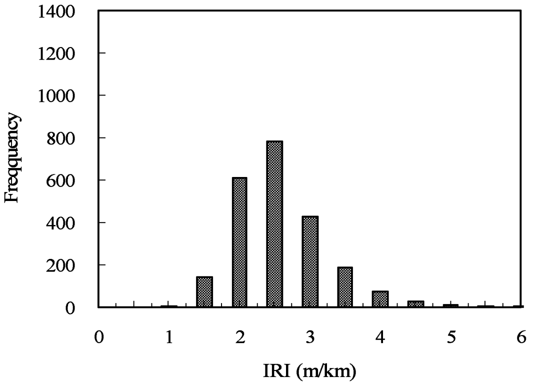


Fig. 10. Distribution of Severity Due to IRI.

One of the assumptions for the multiple regression analysis used for the development of the model equation is that the dispersion of the error term is constant, and the Line of Equality in Fig. 7 indicates that the error term is dispersed randomly, indicating that the model equation for NHPCI is valid and appropriate.

Sensitivity of NHPCI

Sensitivity analysis was carried out to find out the influence of each independent variable on NHPCI. The analysis used data of automated road analyzer on 22,000 road sections collected by Korean national highways PMS in 2007. The distribution of the severity of each distress is shown in Figs. 8 to 10. The actual data collected from the automated road analyzer at 22,000 road sections were substituted to the model equation for NHPCI. Then, the data result was used for the sensitivity analysis. The sensitivity analyses for the three independent variables were conducted by setting the severity (High, Medium, and Low) of each pavement distress on the x-axis and the corresponding NHPCI value on the y-axis.

Here, the severity of each pavement distress on the x-axis was set assuming that the severities of each pavement distress are normally distributed. Actually it was found after several normality test such as Anderson-Daring, Shapiro-Wilk, and Kolmogorov-Sminov tests that only the rut depth and the roughness (IRI) distribution are said to be normal. But the crack distribution was also assumed to be normal for convenience in this study. The borderline for 20, 50, and 80% probability was set to Low, Medium, and High, respectively, as shown in Fig. 11. The severity value for each pavement distress is shown in Table 8.

The severity of independent variables, which was classified into Low, Medium, and High, as pavement distress were substituted to the model equation of NHPCI in order to find out the effect of each independent variable on the dependent variable of the model equation. All other variables except the independent variable related to the sensitivity of the dependent variable took their average value. The result is shown in Fig. 12, and the sensitivity to each independent variable can be inferred by comparing the slope of graph. In other words, steeper slope means that independent variable had greater influence on NHPCI. The result indicates that the independent variables were influential in the descending order of IRI, Rut depth, and Crack at the severity range between Low and

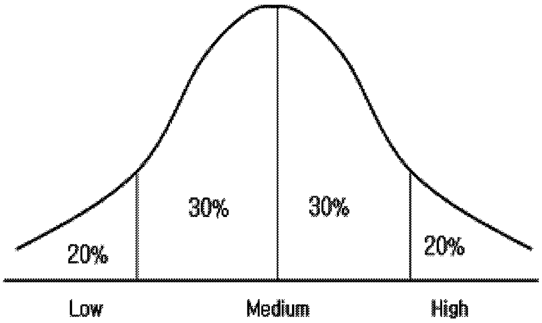


Fig. 11. Probability Range of the Severity (Low, Medium, and High) for Each Pavement Distress.

Table 8. Sensitivity Analysis Value (Severity - Low, Medium, and High) for Each Pavement Distress.

Severity	Crack (%)	Rut Depth (*mm*)	IRI (*m/km*)
L	0	4.7	1.95
M	10.84	8.97	2.54
H	24.35	10.23	3.13

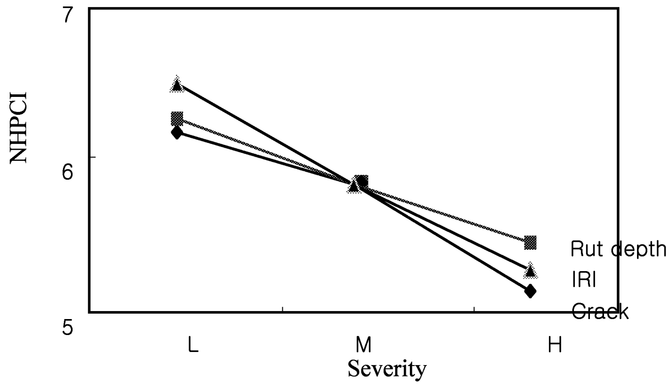


Fig. 12. Sensitivity Analysis of the NHPCI by Pavement Distress Type.

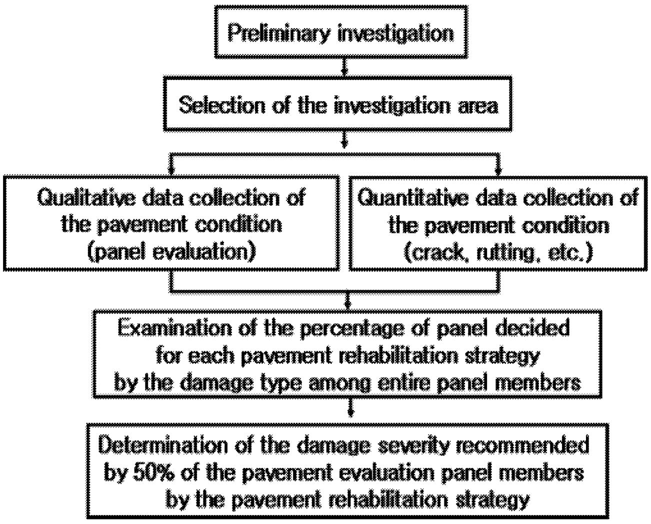


Fig. 13. Flowchart for the Determination of the Threshold Value for the Selection of Proper Pavement Rehabilitation Strategy by Using Pavement Distress Type.

Medium while the descending order changed to Crack, IRI, and Rut depth for the severity range between Medium and High.

Determination of Criteria for Pavement Resurfacing

The purpose of the determination of threshold value by each pavement distress is to determine the appropriate bound value for the selection of proper rehabilitation method by each pavement distress type. The flowchart for the determination of the threshold value for the selection of proper pavement rehabilitation method by using pavement distress type in this study is shown in Fig. 13.

The threshold value for the resurfacing of each pavement distress type was determined from the panel ratings, which was used in the development of the NHPCI model as discussed earlier. After investigating the portion of the panel members (Panel %), each rehabilitation method (mill and resurfacing, resurfacing, surface treatment, or crack sealing) is determined based on the value at which 50% of panel members concurred was set to be the threshold for the rehabilitation strategy for that particular pavement distress (crack, rutting, pothole, or roughness), where was selected from those 40 investigation road sections. This means over 50% of panel members recommended this threshold value for each pavement rehabilitation strategy for that particular pavement distress.

In order to determine the threshold values of the pavement distress by resurfacing method as recommended by 50% of pavement evaluation panel, the statistical program package, SAS was conducted for finding the correlation (R-square) of pavement condition values (rutting, crack percentage) and percentage of panel recommendation of resurfacing. As a result, sealing (R^2 of 0.25 with crack percent) and surface treatment (R^2 of 0.40 with crack percent and 0.31 with rut depth) were not included in the analysis due to their low correlation with panel ratings.

Therefore, this study derived the threshold value for mill-resurfacing (inlay) and resurfacing (overlay) against rut depth and the threshold value for resurfacing against crack percent, and the results are shown from Figs. 14 to 16.

Fig. 14 indicates that over 50% of panel members recommend for mill and resurfacing for the case of rut depth greater than 12*mm*. Likewise, Fig. 15 shows that over 50% of panel members recommend for resurfacing for the case of rut depth between 11 and 12*mm*. Finally, Fig. 16 indicates that over 50% of panel members recommend for resurfacing for the case of crack percent greater than 20%.

Conclusions

This paper developed a model equation for the representation of various pavement distresses such as crack, rutting, and roughness (IRI) as one combined index for the pavement management system of Korean asphalt national highway at network level. The model equation also suggested the threshold values of rut depth and crack percent for the requirement of resurfacing work. The following conclusions are derived within the scope of this study.

(1) Pavement evaluation scores rated by ten pavement evaluation panel members and the pavement condition values collected from an automated road analyzer were statistically analyzed to develop NHPCI (National Highways Pavement Condition

Index). NHPCI was represented as a function of roughness (IRI), rut depth, and crack percent, and R^2 value for the developed model was 0.78.

(2) The result of the sensitivity analysis of the NHPCI model equation indicates that the independent variables were influential in the descending order of IRI, Rut depth, and Crack at the severity range between Low and Medium while the descending order changed to Crack, IRI, and Rut depth for the severity range between Medium and High.

(3) Over 50% of panel members recommended that for rut depth greater than 12*mm*(threshold value), mill-resurfacing (Inlay) is required.

(4) Over 50% of panel members recommended that for rut depth in between 11 and 12*mm*(threshold value), resurfacing (Overlay) is required.

(5) Over 50% of panel members recommended that for percentage of crack greater than 20%(threshold value), resurfacing (Overlay) is required.

The NHPCI model equation developed in this study will be applied to monitoring of pavement condition of Korean national highway as well as determination of maintenance priority for each road section of national highway, selection of rough pavement rehabilitation method, the basis for the pavement maintenance budget, and the development of pavement performance model, etc. Moreover, it is expected that the threshold values for pavement rehabilitation strategy by each pavement distress on national highway will be used as an objective basis for the Korean PMS maintenance procedure guide.

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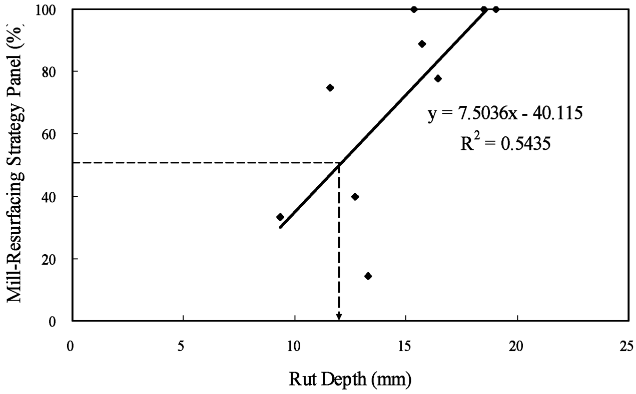

Fig. 14. Threshold Value of Rut Depth for the Application of Mill-Resurfacing Strategy.

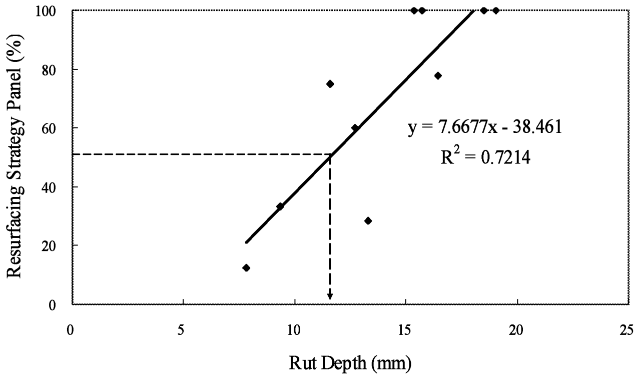

Fig. 15. Threshold Value of Rut Depth for the Application of Resurfacing Strategy.

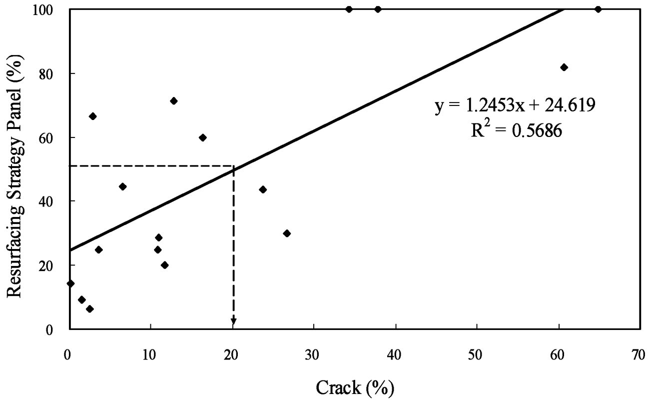

Fig. 16. Threshold Value of Crack Percent for the Application of Resurfacing Strategy.