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MODELING OF ROAD PERFORMANCE ASSESSMENT BASED ON PAVEMENT, SHOULDER, AND DRAINAGE

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Measuring the value of road performance requires an emphasis on optimal performance demand. In Indonesia, pavement assessment is the sole basis for evaluating performance value. However, road performance is not solely determined by pavement performance, as the performance of road shoulder and drainage systems also influences it. This study aims to create a road performance evaluation model that is quantitative in nature, taking into account both pavement performance and the frequency and size of damages to road shoulders and drainage systems. To construct the model, this study employed a Structural Equation Model. According to the findings, the condition of the road shoulder and drainage systems had an impact on the road's performance, as measured by the International Roughness Index (IRI). The subsidence factor had the most significant impact on road shoulder performance (31.1%), then followed by waterlogging (29.4%), potholes (29.2%), and pavement edge height difference and road shoulder (5.3%), in addition to shoulder slope (5.0%). The road drainage performance, on the other hand, was influenced by the cross-sectional conditions of the road drainage channel (34.6%), structural drainage (31.1%), and drainage canal slope (29.2%). The study found that pavement, road shoulder, and drainage had a respective effect of 58.1%, 20.2%, and 21.7% on road performance.

Keywords: road performance, pavement, shoulder, drainage

1 INTRODUCTION

Based on the Law of the Republic of Indonesia, Number 02 of 2022 (2022) [23], public roads are classified based on their status; national, provincial, city, regency, or village. Arterial roads and collector roads are the national roads. In the primary road network system, these roads connect between the provincial capital, national strategic roads, and toll roads. The jurisdiction of road administrators (referred to as Indonesian governments) is divided based on the road status. The national government has the authority to manage general and national road maintenance. The regional government is authorized to oversee the maintenance of provincial, city, regency, and village roads. Following the national strategy for road maintenance, the maintenance of road generally comprises regulation, direction, development, and macro supervision. Through the Ministry of Public Works and Public Housing, the government is attempting to preserve road performance by performing ongoing road maintenance so that the vital role of roads may continue to function ideally and the goal of enhancing connectivity can be accomplished.

The International Roughness Index (IRI) determines road stability (Bilodeau, Gagnon, & Doré, 2017)[5]. Surface Distress Index (SDI) and Pavement Condition Index (PCI) are also used to assess road pavement performance (Hasibuan & Surbakti, 2019) [13]. The Present Serviceability Rating (PSR) and Pavement Quality Index (PQI) are other methods for measuring road pavement performance indicators (Imam, Murad, & Asi, 2021) [15]. Among the quantitative measures of the roughness of a pavement surface, IRI is the most frequently used criterion for evaluating pavement performance and determining pavement maintenance or rehabilitation policies (Sharma, Sachdeva & Aggarwal, 2023) [26].

Evaluation of road pavements by measuring the pavement surface roughness is conducted to define IRI, while SDI and or PCI are used to calculate surface tension (Shrestha and Khakdka, 2021) [27]. Table 1 shows the comparison of the IRI threshold conducted by different studies.

Assessment of road conditions in several other countries, on average, uses IRI and SDI values. However, there are differences in the criteria for assessing indicators (Piryonesi, El-Diraby, 2021 [20]; Shahid, 2019 [25]; Patrick and Soliman, 2019 [19]; Asada, Ha, Arimura, Kameyama, 2022 [2]; Arianto & Suprapto. 2018 [1], France-Mensah, O'Brien, 2019 [8]). The range of values for a good condition of a road section in one country differs from in other countries. IRI and SDI's value range in Indonesia varies from several different countries. Developed countries such as the USA define the range of condition values in a shorter value with an IRI value greater than 5, indicating a poor condition. In contrast, in Indonesia, the IRI value above 12 only shows the same criterion of poor conditions. The whole comparison criteria for IRI and SDI values in Indonesia and several other countries are shown in Table 2.

Table 1. Comparison of the IRI threshold conducted by previous studies

Road Condition	IRI (m/km)		
	Aleadelat et al. 2018 [3]	Rusmanto et al. 2018 [24]	Hasanuddin et al. 2018 [12]
Excellent	<1.10	-	-

Road Condition	IRI (m/km)		
	Aleadelat et al. 2018 [3]	Rusmanto et al. 2018 [24]	Hasanuddin et al. 2018 [12]
Good	1.10 – 1.56	≤ 3.5	≤ 4.0
Fair	1.60 – 2.05	3.5 – 5.8	4.1 – 8.0
Poor/Damaged	2.07 – 2.68	5.8 – 9.0	8.1 – 12
Very Poor/Seriously Damaged	2.68 <	9.0 <	12 <

Table 2. A comparison of the criteria for evaluating road conditions among multiple countries

Classification	Indonesia	Malaysia	USA	Canada	Belgium, Portugal, Japan, France
IRI	< 4 (*Very Good*)	< 2 (*good*)	2 (*Excellent*)	< 1 (*Excellent*)	0-2 (*very good*)
	4 – 8 (*Good – Fair*)	3-5 (*fair*)	2-2.5 (*Good*)	1.0-1.5 (*Good*)	2-4 (*good*)
	8 – 12 (*Fair – Poor*)	> 5 (*poor*)	2.5-3.8 (*Fair*)	1.5 -2 (*Fair*)	8-11 (*Average*)
	12 -16 (Poor – Bad)	-	> 3.8 (*Poor*)	> 2 (*Poor*)	11-12 (*Bad*)
	16 – 20 (Bad)	-	-	-	-
	> 20 (*Very bad*)	-	-	-	-
SDI	< 50 (*Excellent*)	-	< 77 (*Excellent*)	-	-
	50 – 100 (*good*)	-	77 – 87 (*good*)	-	-
	100 – 150 (*fair*)	-	88 – 97 (*fair*)	-	-
	> 150 (*poor*)	-	≥ 98 (*poor*)	-	-

Most countries use IRI or SDI for the evaluation of road performance. However, accurately predicting IRI values on the road network becomes problematic when the length of the road network reaches hundreds of kilometers (Sharma, Sachdeva, & Aggarwal, 2023 [26]). Evaluation of the performance of a road section, especially in Indonesia, is still based on the pavement; hence it is necessary to concentrate on other road components, such as road shoulders and drainage. Road shoulder and drainage are units that influence each other. Poor drainage and shoulder conditions affect other components (Dafalla, Shaker, & Al-Shamrano, 2022 [7]).

Halomoan et al. (2018) [11] carried out a study on the impact of each type of damage on the performance of road shoulders and drainage. However, they did not developed a quantitative method to assess the performance of road shoulders and drainage. Additionally, there is a lack of studies on how the frequency and magnitude of damage to road shoulders and drainage systems affect road performance. Therefore, there is a pressing need to develop models that can evaluate road shoulder and drainage performance in a quantitative manner, as this will enable a more accurate assessment of overall road performance.

Evaluation of performance indicators for road pavement indicates that the pavement should not have any of the following five types of damage: potholes, cracks, sinking, unevenness after resurfacing, and grooves/rutting. Research states that road shoulders and drainage play an essential role in road performance, capacity, and safety. Sutradhar and Pal (2020) [29] argue the main factors affecting the performance of road shoulder pavements are the width of the road shoulders, compaction, the slope of the road shoulders and differences in the height of the road shoulders which are not following the provisions. In their most recent study, Novel and Putranto (2020) [18] assert that road preservation is most significantly impacted by road drainage.

The performance score of road pavement, comprising of IRI, SDI, and PCI, fully compensates for the damage. However, these indices, which serve as theoretical references for road pavement performance, do not explain the overall road performance since other road components, such as road shoulder and drainage, may also have strategic roles and responsibilities. This study aims to develop a model for assessing preservation performance to address research gaps and meet the current concept's needs. The constructed model would provide a method for evaluating road section performance, including road pavement, shoulder, and drainage quality. Additionally, the model would offer solutions for assessing road shoulder and drainage performance based on the frequency and magnitude of damage.

2 METHODS

2.1 Analysis Methods

The present study collected respondents' perspectives through interviews and a questionnaire and analyzed them quantitatively. At the same time, a pavement performance evaluation model that accounts for the level of road pavement, shoulder, and drainage damage was produced based on the analysis results of the survey processed using statistical approaches. Structural Equation Modeling (SEM), a multivariate statistical analysis technique in the present study, was used to form correspondence of data relationships in the theoretical model. The SEM model is more suitable for testing hypotheses than other statistical methods (Civelek, 2018) [6]. SEM differs from regression data processing and path analysis because it might accept more complex data generated by measurement and structural models (Hayes, Montoya, & Rockwood, 2017) [14]. Five steps are required for SEM analysis: 1) model specification; 2) model identification; 3) model estimation; 4) model evaluation; and 5) model modification or re-specification. In addition to SEM, this study employed descriptive statistics and factor analysis (Thakkar, 2020) [31].

2.2 Data Collection Technique

The primary data were collected through interviews with respondents who traveled on national highways and monitoring the functioning of national roads. On the other hand, the secondary data were collected from various institutions associated with road administration. This study utilized a fixed respondent design because the target respondents were predetermined, and there were no changes made when respondents were withdrawn. Cluster sampling was employed to select respondents from small groups or units (Rahman et al., 2022) [22]. The two-stage cluster sampling technique was utilized.

2.3 Characteristics of Respondents

The focus of this study was on individuals involved in the development and examination of long-segment road and bridge preservation packages, covering the planning, design, implementation, and various research object components. With a population of 140, a sample size of 124 respondents was computed to achieve a 99% accuracy rate with a 1% margin of error. However, due to stakeholder changes, the number of research participants was increased to 125. Please refer to Table 2 for the number of respondents and their criteria as the target of the primary data survey.

Table 3. Characteristics of respondents

Position	Number of respondents
National Road Implementation Board	9
National Road Implementation Unit	18
National Road Planning and Supervision Work Unit	8
Commitment-Making Officer of Long Segment Package	18
Contractor	18
Planning Consultants	18
Supervising Consultants	18
Experts/Academics	18
Total	125

2.4 Data Analysis

This study employs several data analysis techniques, including descriptive statistics, factor analysis, and SEM method analysis. The profile or performance of the road, as well as the intended quality assurance, are described using descriptive statistical analysis. Existing conditions are initially analyzed utilizing descriptive statistics. With descriptive statistical data, factor analysis and SEM procedures will become more focused and systematic in their modeling (Tarka, 2018) [32]. Factor analysis is a statistical model that employs correlation and covariance relationships among variables to explain or summarize the group of variables as a collection of unobserved random quantities known as factors (Bandalos & Finney, 2018) [4].

3 DISCUSSION

Validity and reliability tests were performed on the research data to determine its quality. The validity test measures the extent to which the data from a questionnaire measures what is intended to be measured. At the same time, the reliability test estimates the consistency of the measuring instrument—for example, whether the measuring device used is reliable and remains consistent when repeated measurements are made. The essential features of a scale are validity and reliability. The validity test focuses on the quality of the measuring instrument to carry out its function as a measuring instrument in several trials. Reliability is a stability indicator of the measured value obtained in repeated measurements under the same conditions (Sürücü & Maslakci, 2020) [28]. See table 4 for results of validity and reliability tests conducted on 125 respondents.

Table 4. Results of Validity test

Code	Construct	Pearson	t-Count	t-Table	Note
P1	There should be no potholes on the surface of the asphalt pavement with a diameter of > 10 cm and a pothole depth of > 4 cm	0.901	30.04	1.665	Valid
P2	There should be no structural cracks on the asphalt pavement surface with a width of > 6 mm and/or a structural crack area of > 5% per 100 m	0.886	29.96	1.665	Valid
P3	There should be no non-structural cracks on the asphalt pavement surface with a width < 6 mm and/or structural crack area > 10% per 100 m	0.896	30.12	1.665	Valid
P4	There should be no subsidence of asphalt pavement with a depth of > 3 cm and/or a collapsed area of > 5% per 100 m.	0.892	30.00	1.665	Valid
P5	There should be no rutting parts of the asphalt pavement (corrugated wheel grooves) with a depth > 10 mm	0.887	29.928	1.665	Valid
P6	There should be no raveling (loss of aggregate granules) on the asphalt pavement surface with raveling areas > 5% per 100 m	0.89	30.056	1.665	Valid
P7	There should be no cracks on the rigid pavement surface in width > 3 mm and/or crack area > 5%	0.894	29.968	1.665	Valid
P8	There should be no faulting of the rigid pavement surface	0.887	30.12	1.665	Valid
P9	Rigid pavement joint sealants are in good condition and should not be broken or lost in all slab joints between concrete slabs	0.888	29.96	1.665	Valid
P10	There should be no corner breaks on the rigid pavement surface in width > 6 mm	0.897	30.088	1.665	Valid
B1	There should be no shoulder holes with a diameter of > 20 cm and a depth of > 10 cm	0.843	16.616	1.042	Valid
B2	There should be no shoulder tilt > 6%	0.851	16.728	1.042	Valid
B3	There should be no height difference of > 5 cm between the shoulder elevation and pavement edge elevation	0.835	16.648	1.042	Valid
B4	There should be no puddle on the shoulder of the road when it is not raining	0.855	16.536	1.042	Valid
B5	There should be no subsidence of the shoulder surface with a depth of > 10 cm and an area of > 3% per 100 m road shoulders	0.845	16.528	1.042	Valid
B6	There should be no road shoulder elevation higher than the pavement edge elevation	0.85	16.544	1.042	Valid
D1	There should be no drainage channel with structural damage	0.827	6.48	0.336	Valid
D2	There should be no wet cross-section of the drainage channel that is clogged > 10% of the channel capacity	0.774	6.48	0.336	Valid
D3	There should be no road drainage channels with puddles when there is no rain, or the slope towards the flow is less able to drain water	0.837	6.384	0.336	Valid

3.1 Validity Test

A validity test was conducted on the questionnaire data using Pearson Bivariate or Pearson product-moment correlation, where each variable score is correlated with the overall score (Swank & Mullen, 2017) [30]. To establish the significance of the correlation, the correlation coefficient (r-count) was collated to the t-count and t-table values of the t-test. The presence of significant correlations between the total score and the variables implies that these variables are valuable in recognizing the factors that impact road performance. The validity test, which utilized a two-tailed test at a 5% significance level, is presented in Table 4, demonstrating that the questionnaire data on pavement, drainage, and shoulders are valid. The t-count values of all criteria exceeded the t-table values, indicating that all indicators are applicable for assessing the effects of pavement, drainage, and shoulders.

3.2 Reliability Test

The reliability test measures the extent to which a measuring tool can generate consistent results when multiple measurements are taken on the same object (Puig-Divi, Escalona-Marfil, Padulles-Riu, Busquets & Padulles-

Chando, 2019) [21]. The minimum reliability value of acceptable latent variable forming dimensions is ≥ 0.70 (Ghozali, 2018) [10]. The variables in the questionnaire, such as pavement, shoulder, and drainage variables, fulfill the reliability test because each factor has a construct reliability of ≥ 0.70 and even > 0.9, see Table 3.

Table 4. Results of Reliability test

Variable/ Construct	Item	Loading Factor (λ)	Error (ε)	Σ (λ)	Σ (λ^2)	Σ (ε)	Construct Reliability (CR)
Pavement	P1	0.521	0.194	6.899	4.847	1.665	0.966
	P2	0.804	0.113				
	P3	0.609	0.175				
	P4	0.712	0.153				
	P5	0.807	0.108				
	P6	0.705	0.187				
	P7	0.619	0.167				
	P8	0.758	0.200				
	P9	0.769	0.137				
	P10	0.595	0.231				
Shoulders	B1	0.735	0.178	4.353	3.164	1.042	0.948
	B2	0.715	0.193				
	B3	0.772	0.171				
	B4	0.670	0.183				
	B5	0.746	0.156				
	B6	0.715	0.161				
Drainage	D1	0.807	0.127	2.488	2.068	0.336	0.949
	D2	0.886	0.081				
	D3	0.795	0.128				
RSePS	RJ1	0.702	0.199	4.289	3.074	1.129	0.942
	RJ2	0.657	0.214				
	RJ3	0.705	0.202				
	RJ4	0.775	0.151				
	RJ5	0.713	0.204				
	RJ6	0.737	0.159				

3.3 Full SEM Model Analysis

An analysis of the effect of pavement, shoulders, and road drainage on-road performance was conducted using a full SEM model. This model combines between the measurement (factor analysis) and the structural (regression) models. Factor analysis and multiple regression analysis show a constant interaction and model representation (Makransky & Lilleholt, 2018) [17]. Factor analysis is a modeling technique that seeks to elucidate the connection between variables in terms of latent variables or factors. These factors are stochastic entities that were previously unobservable or unmeasurable. Furthermore, factor analysis is employed to uncover the relationship between the components of the factors or dimensions and the factors themselves, by analyzing the correlation coefficients between them and their constituent variables. Factor analysis is a modeling approach that investigates the function of one or more theoretical constructs, also known as latent constructs, which are intangible entities. Since a latent construct cannot be observed directly, factor analysis aims to assist researchers in identifying and comprehending the nature of these constructs. (Bandalos & Finney, 2018) [4]. This analysis is referred to as confirmatory analysis. Figure 1 shows the modeling of the structural relationships between components that contribute to road pavement performance. Figure 2 shows the modeling of the structural relationships between components that contribute to road shoulder performance. Figure 3 shows the modeling of the structural relationships between components that contribute to road segment performance.

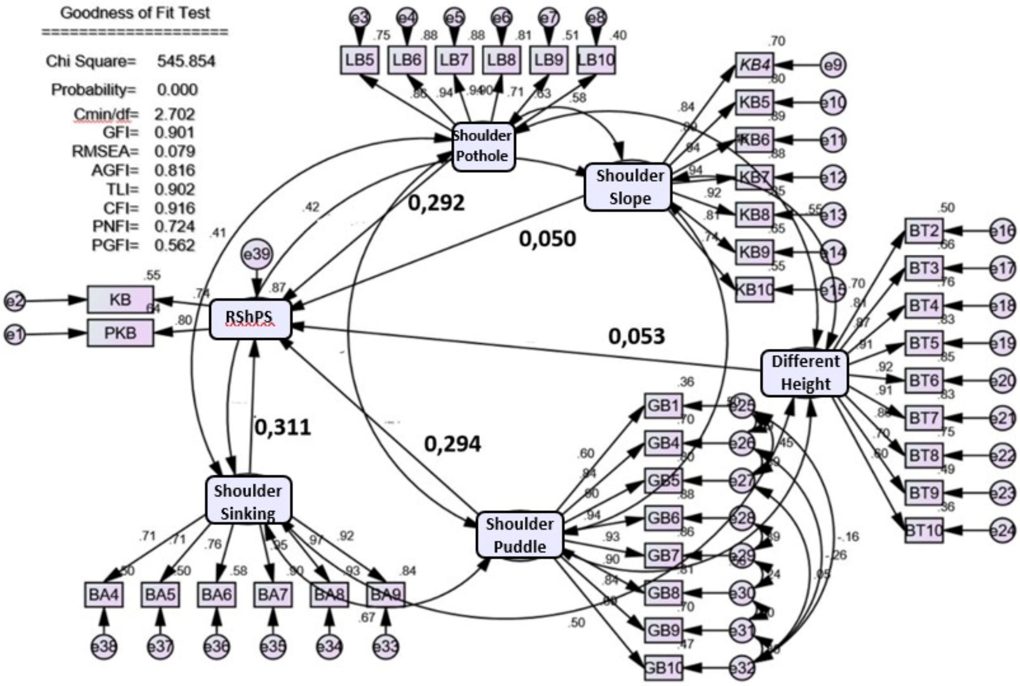

Figure 1. Results of full SEM model analysis of road shoulder performance

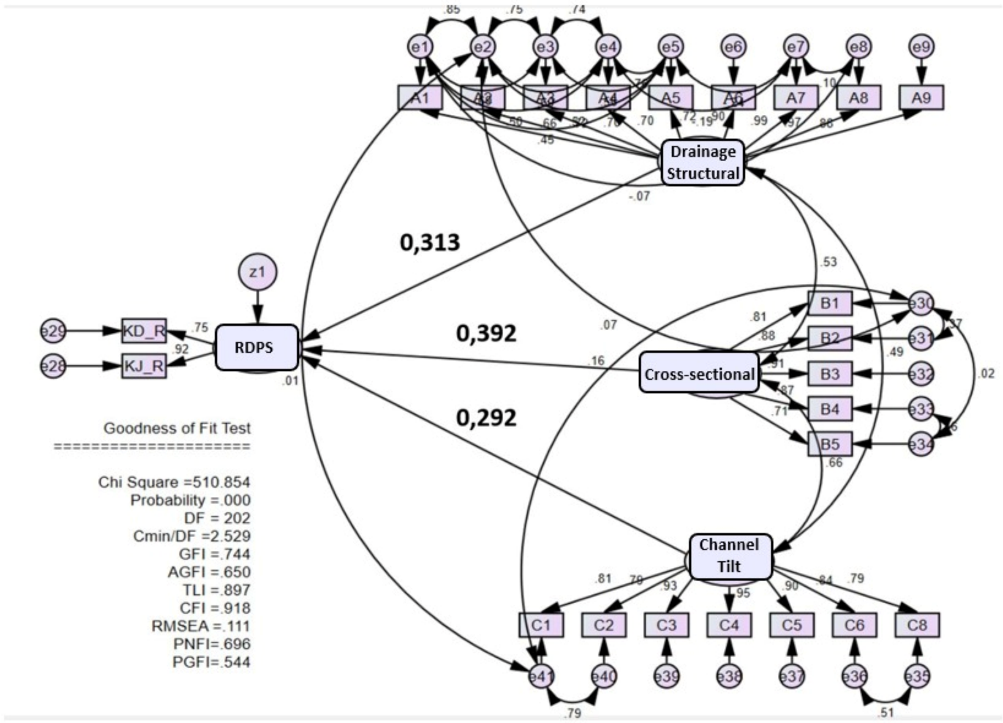

Figure 2. Results of full SEM model analysis of road drainage performance

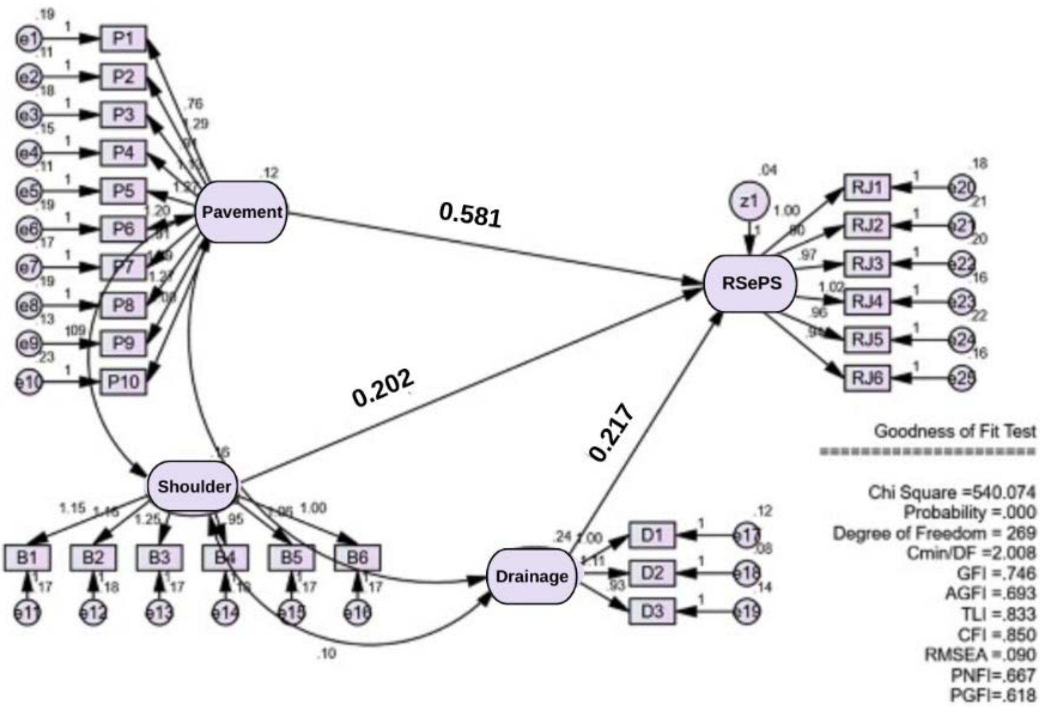

Figure 3. Results of full SEM model analysis of road segment performance.

See Table 5 for a summary of the validity test results of the indicator models that contribute to the road sections' performance.

Table 5. Results of validity tests of the indicator models that contribute to the road performance

Types of Data Validity Test	Standard	Analysis Results	Note
Chi-Square Probability	Significance > 5% (0.05)	0.243	Valid
The Goodness of Fit Index (GFI)	> 0.9 (90%)	0.907	Valid
Adjusted Goodness of Fit Index	> 0.9 (90%)	0.904	Valid
Tucker-Lewis Index	> 0.9 (90%)	0.916	Valid
Root Mean Square Error of Approximation	< 0.08	0.066	Valid

The full SEM model was used to calculate the contribution weight of each factor to the road performance. The results of the SEM analysis of factors and indicators that contribute to road performance can be seen in Table 6.

Table 6. The SEM analysis results of factors that contribute to the road performance

Factors	Influence Weight (β)
Road Pavement Performance	0.581
Road Drainage Performance	0.217
Road Shoulder Performance	0.202

Below are the recommendations from the validation test of the indicator models that significantly contribute to the performance of road sections:

1. Evaluation model of road shoulder performance

RShPS = 100 – (0.311 CS + 0.294 PS + 0.292 PTS + 0.053 LD + 0.050 ST)

where:

RShPS : Road shoulder performance score

CS : Area of collapsed road shoulders/ Total area of monitoring segment (m^2)

PS : Area of puddle on road shoulders/ The total area of monitoring segment (m^2)

PTS : Area of pothole on road shoulder with a diameter of > 20 cm/ Total area of monitoring segment (m^2)

LD : Length difference between elevation of road shoulder and Pavement Edge > 5 cm/ Total length of monitoring segment (m)

ST : Length of road shoulder tilt out of range 4-6%/ Total length of monitoring segment (m)

2. Evaluation model of road drainage performance

RDPS = 100 – (0.346 BD + 0.311 LBD - 0.296 DL)

where:

RDPS : Road drainage performance score

BD : Cross-sectional area of blocked drainage channel/ Total area of monitoring segment (m^2)

LBD : Length of broken drainage structure/ Total length of drainage segment reviewed (m)

DL : Length of drainage channel tilt outside tolerance range/ Length of drainage segment reviewed (m).

3. Evaluation model of road segment performance

RSePS = 0.581 RPPS + 0.202 RhSPS + 0.217 RDPS

where:

RSePS : Road segment performance score

RPPS : Road pavement performance score

RShPS : Road shoulder performance score

RDPS : Road drainage performance score

4 CONCLUSION

Road shoulder performance is influenced by the subsidence factor on the road shoulder at 31.1%, waterlogging at 29.4%, potholes at 29.2%, pavement edge height difference and road shoulder at 5.3%, and shoulder slope at 5.0%. Road drainage performance is influenced by cross-sectional conditions of the road drainage channel contributing at 34.6%, structural drainage at 31.1%, and drainage canal slope at 29.2%. Based on the results, the road pavement has the most significant effect on the road section's performance at 58.1%. In addition, road shoulder and drainage influence road performance by 20.2% and 21.7%, respectively. These results indicate that road shoulder and drainage also contribute to road performance. Since the Indonesian government's primary priority in preserving the performance of road segments is solely on the performance of the road pavement, consideration of shoulder and drainage is strongly recommended to be considered during significant rehabilitation and reconstruction. Therefore, this study suggests that the government evaluate the current policy related to the components affecting road performance. This research is for improving the sustainability of road pavements and identifying, through appropriate methods, priority handling of these road pavements, thereby increasing the performance of maintenance and rehabilitation activities.

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