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ENHANCING ROAD PERFORMANCE MEASUREMENT IN INDONESIA: PROPOSED CHANGES AND FUTURE DIRECTIONS

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This research aims to evaluate the fulfillment criteria of road performance indicators in the current long segment scheme in Indonesia by considering road performance indicators in other countries in PMBC. The research utilized the Confirmatory Factor Analysis (CFA) model in Structural Equation Modeling (SEM). The respondents were service providers and users, and the sampling technique was random. The study found that all significant road performance indicators affect the latent variable, based on the evaluation of road performance indicators listed in the 2018 Revision 2 General Specification of the Ministry of Public Works and Housing that are currently in effect. The CFA on 40 road performance indicators indicates that nine indicators do not have a significant influence on road performance. Therefore, only 31 indicators are proposed concerning response time. In addition, new road performance indicators, such as uneven patching, raveling, and dirty drainage, are proposed to be included. Response time to the indicators also needs to be updated based on service users' and providers' questionnaire survey results. This study provides valuable information for policymakers and stakeholders to improve road preservation outcomes in Indonesia.

Keywords: road performance indicators, fulfillment criteria, confirmatory factor analysis, road preservation outcomes

1 INTRODUCTION

AASHTO [1] defines road maintenance as a program for maintaining, repairing, and restoring road systems and their components to achieve the ideal condition as designed or acceptable conditions. Routine maintenance is crucial for road service and capacity [2]. The quality of road infrastructure deteriorates structurally and functionally over time, as expected in its design life. Therefore, a road maintenance program with adequate and sustainable planning and funding is needed to implement the road maintenance system accurately and optimally. Maintenance components include road surface pavement, shoulders, edges, drainage facilities, bridges, tunnels, signage, markings, and lighting. The World Road Association [3] states that road maintenance is the activity of maintaining road pavement, shoulders, slopes, drainage facilities, and all other structures and components within the road boundaries as close as possible to the conditions when they were built (as-built) or their most recent conditions. This includes minor repairs and fixes to eliminate causes of damage and avoid excessive maintenance repetition but does not include rehabilitation, shoulder construction, or road widening.

The performance indicators of roads currently applied in Indonesia still exclude several damages not included in the road service level criteria. Therefore, an evaluation of the current road performance indicators is necessary. The road performance indicators currently applied in Indonesia are still not targeted accurately. Some applied indicators focus on the quantity and length of roads, while the quality and condition of roads remain problematic and have not been adequately addressed. The road performance indicators applied in Indonesia are still not integrated with existing strategic policies. This causes the road performance indicators to lack clear objectives and not contribute to achieving broader goals in developing better road infrastructure.

Evaluation of road performance indicators in Indonesia is crucial to improve the effectiveness of transportation systems, enhance road users' safety and security, increase road users' satisfaction, and improve Indonesia's competitiveness in the transportation sector. Road performance indicators are critical in measuring the effectiveness of transportation systems because roads are the primary infrastructure in Indonesia's land transportation system. Evaluating road performance indicators can help determine whether the transportation system is adequate or needs improvement. Evaluating road performance indicators can also help identify problems and improvement needs on the road. By knowing the unsatisfactory performance indicators, improvements can be made to enhance road performance. With good road performance indicators, Indonesia can increase its competitiveness in the transportation sector. Good road infrastructure can improve efficiency and productivity in economic activities, such as transporting goods and services.

Starting in 2016, the implementation scheme for preserving national roads in Indonesia, mainly routine maintenance of roads that were previously handled independently by each Commitment Maker Officer in their capacity as road section managers, changed to a long segment scheme. The Indonesian Directorate General of Highways implemented the long segment scheme as part of the national road preservation program, combining routine maintenance work, routine road and routine condition, and preventive and holding work, with widening, rehabilitation, and reconstruction of several road segments into a single contract. The definition of road preservation in Indonesia differs from that practiced in developed countries, which generally involves maintaining established roads.

Based on the literature review conducted, there are similarities between the long segment system and the Performance-Based Contract (PBC). Both involve construction work based on performance, which means maintaining a specific performance level within a predetermined period. The difference lies in the scope of work and the maintenance period. The scope of work in the long segment system does not include design work and has a shorter maintenance period than in the PBC system.

Performance-Based Maintenance Contract (PBMC) is a procurement system where payment is based on performance and time of work [4]. PBMC was first implemented in Canada in 1988. In 1990, Argentina began using PBMC for a 1,000 km road, applying performance specifications for maintenance and penalty systems for failure to respond within the designated timeframe [5]. In the 1990s, Australia, the United States, Uruguay, Montevideo, Latin America (Brazil, Chile, Colombia), Ecuador, Guatemala, Peru, and New Zealand began implementing PBMC. The World Bank, as an international financial institution, first supported PBMC in 2002 and has since funded 200 PBMC projects [6]. In PBMC, service performance and output indicators are the main characteristics [7], so performance indicators must be carefully established, considering road conditions, road equipment, geographic conditions, road user needs, service user expectations, and costs [8].

Anastasopoulos et al. [9] explained that in a traditional method-based contract, the road owner determines the techniques, materials, methods, quantity, and duration of the contract, while in a PBMC, the road owner sets the minimum performance standards that must be met or exceeded during the contract period. The quality of work produced through the PBMC mechanism is better than maintenance work done under other types of contracts because payment is not based on the quantity of work but on performance indicators. Therefore, performance indicators should explain criteria, service quality, measurement, and response time [10]. PBMC defines the contractor's success in meeting the set performance targets. PBMC is intended to encourage contractor innovation and improve quality by promoting value engineering and efficiency improvements [4].

Assessment of user satisfaction level and implementation success in road preservation concept (maintenance, rehabilitation, reconstruction, and widening) from technical and non-technical aspects are difficult to measure because there is no performance indicator. However, with the implementation of a long segment scheme in road preservation, there is a primary performance indicator in measuring the achievement of road preservation [11]. Performance indicators cannot stand independently but must be interrelated, which means that the performance indicators of road preservation outcomes are directly related to the behavior of project implementers, supervisors, and controllers. All performance matrices must be measurable, easily understood and implemented, and accompanied by appropriate and fast technical solutions. Therefore, this study aims to evaluate the fulfillment criteria of road performance indicators in the current long segment scheme in Indonesia by considering road performance indicators in other countries in PMBC.

2 METHODS

This research used the Confirmatory Factor Analysis (CFA) model in Structural Equation Modeling (SEM). Widhiarso [12] stated that the purpose of CFA is to find a suitable model that describes the correlation between a group of items and the construct of the item assessment. CFA evaluates indicators that explain a latent variable (construct) that cannot be directly estimated. Essentially, CFA is used to test correlations to find relationships between variables. The CFA analysis approach calculates loading factors between the ξ factor produced with the X indicators.

CFA is designed to assess the multidimensionality of a theoretical construct. The empirical analysis is conducted to validate the model that has been built and estimate the sizes that are formed according to theory [13]. There are two basic tests for measuring the model in CFA: (1) a test of the appropriateness of the measurement model and (2) a test of the significance of factor weights or convergent validity (loading factor or λ). The construct validity test is used to validate that the variables produced can simultaneously explain a latent variable with other variables, with factor weights as the criteria for the CFA test. According to Ghozali [13], the convergent validity criteria assessed to have good validity is 0.70, while a value of 0.50-0.60 is still acceptable. This study uses a cut-off point of 0.50; if the factor weight is less than 0.50, the indicator forming the construct is considered not dimensionally the same as the other indicators in describing a construct. This research model applies six constructs, namely road pavement, road shoulders, drainage, road equipment, complementary buildings, and clearance, with indicators shown in Table 1. The indicators contained in Table 1 are processed from various sources, including the 2018 Revision 2 General Specification of the Ministry of Public Works and Housing [14], the Asian Development Bank [15], the World Bank [16], Karlaftis and Kepaptsoglou [17], Zietlow [18], the European Bank [19], Sutradhar and Pal [20], Zietlow [21], and Babić et al. [22].

The respondents in this study were service providers and service users, with a total of 149 individuals. The sampling technique used was random sampling, with the criterion that the respondents were employees and project managers in the working area of the National Road Implementation Center of the Central Java and Special Region of Yogyakarta.

The model that has been developed is then evaluated based on several suitability criteria called Goodness-of-Fit (GOF) criteria. According to Ghozali [13], GOF, or the measurement of the suitability of observed or actual inputs (covariance or correlation matrices) with indices to evaluate the model's feasibility, is shown in Table 2. The final step involves interpreting and modifying the model if it does not meet the applied test requirements. The adjustment aims to determine improvements in theoretical explanation or GOF or reduce the chi-square value due to the applied changes. Generally, the smaller the chi-square value, the more the model fits the available data.

Table 1. Indicators for each construct in SEM

Construct	Measurable Variables/Indicators	Code
Road Pavement	Potholes, diameter < 10 cm, depth < 4 cm	X1
	Potholes, diameter > 10 cm, depth > 4 cm	X2
	Cracks, width < 3 mm, area 5% per 100 m	X3
	Cracks, width > 3 mm, area 5% per 100 m	X4
	Sinkhole, width < 3 cm, area 5% per 100 m	X5
	Sinkhole, width > 3 cm, area 5% per 100 m	X6
	Unevenness of pavement, IRI < 4 mm/m	X7
	Rutting/Depressions, depth 6-13 mm	X8
	Rutting/Depressions, depth 13-25 mm	X9
	Rutting/Depressions, depth > 25 mm	X10
	Raveling	X11
	The brittle edge of the pavement	X12
	Uneven patching	X13
Road Shoulders	Potholes, diameter < 20 cm, depth < 10 cm	X14
	Potholes, diameter > 20 cm, depth > 10 cm	X15
	Elevation, height difference with pavement edge < 5 cm	X16
	Elevation, height difference with pavement edge > 5 cm	X17
	Sinkhole, depth < 10 cm, area > 3% per 100 m	X18
	Sinkhole, depth > 10 cm, area > 3% per 100 m	X19
	Ponding on road shoulders	X20
Drainage	Dirty drainage channel	X21
	Structural damage on the drainage channel	X22
	Less than 10% blockage in drainage channels	X23
	More than 10% blockage in drainage channels	X24
	There is deformation and erosion on the embankment slope, and it is not functioning properly	X25
	Unstable excavation slopes, unable to withstand erosion, and do not function effectively	X26
Road Equipment	The Warning Signs and Traffic Signs are not correctly installed according to regulations, are structurally unstable, and some of the poles are bent	X27
	Not installing temporary signage to prevent traffic accidents caused by unrepaired road damages	X28
	The horizontal separator on the median or sidewalk is not sturdy and not functioning properly	X29
	The horizontal separator on the median or sidewalk surface is not visible at night	X30
	The road markings are unclear and faded	X31
	Guardrails are structurally unsound, improperly installed, and have incurred damage	X32
Complementary Structure	Driveway Approach: there is a settlement of more than 5 cm from the planned elevation of the approach surface	X33
	The Retaining Wall shows no structural damage and functions properly	X34
	Retaining Wall experiences cracking on the wall and foundation	X35
	Retaining Wall experienced a structural failure that resulted in damage to the building structure	X36
Clearance	There are wild plants on the right-of-way of the road	X37
	Wild plants with a height > 10 cm within the road right-of-way or obstructing sight distance for road user safety	X38
	There is an advertisement/banner that obstructs the line of sight	X39
	Debris, trash, sand/soil, rubble, or other obstructions exist	X40

Table 2. Feasibility model testing index

Goodness-of-Fit Index	Cut-off Value
Chi-square	Expected to be small (below the value in the table)
Significance	≥ 0.05
Cmin/df	≤ 2.00
GFI	≥ 0.90
RMSEA	0.05-0.08
AGFI	≥ 0.90
TLI	≥ 0.90
CFI	≥ 0.90
PNFI	≥ 0.50
PGFI	≥ 0.50

3 RESULTS AND DISCUSSION

3.1 CFA Results Among Exogenous Constructs

Exogenous variables in the proposed theoretical framework model indicate that there are six exogenous variables, namely: (1) the exogenous variable of road pavement with 13 observed variables; (2) the exogenous variable of road shoulders with seven observed variables; (3) the exogenous variable of drainage with six observed variables; (4) exogenous variable of road equipment with six observed variables; (5) exogenous variable of complementary buildings with four observed variables; and (6) exogenous variable of clearance with four observed variables. The initial process in conducting confirmatory tests between exogenous constructs is that the exogenous variables must be covaried, as illustrated in Fig. 1.

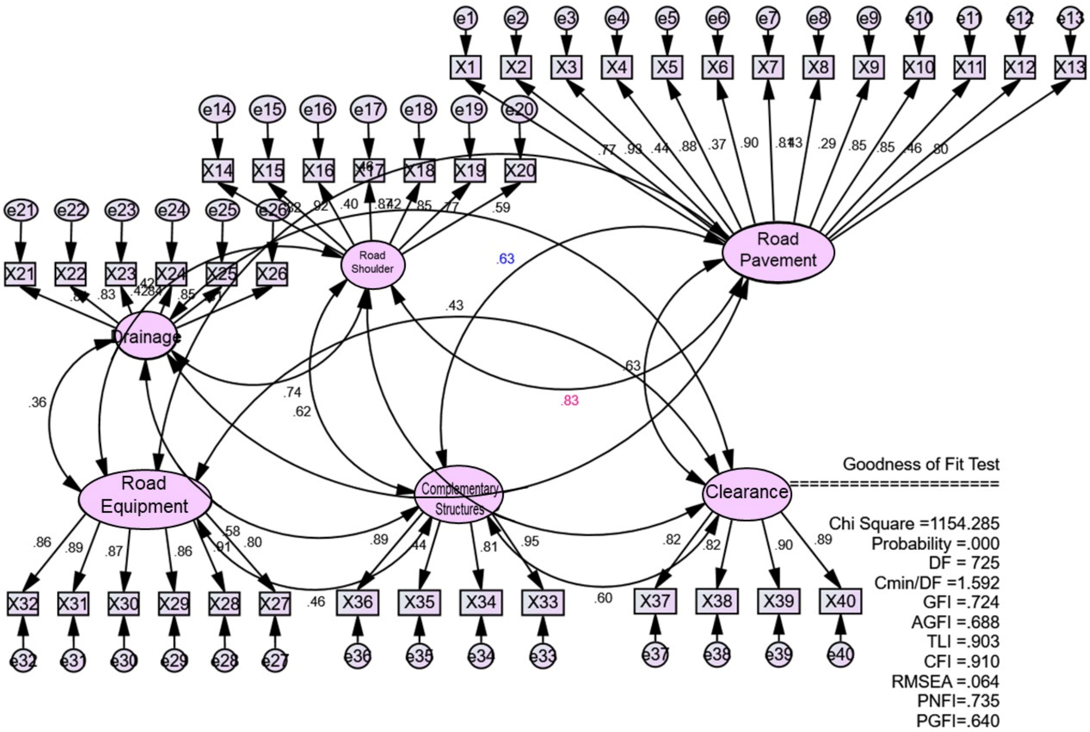

Fig 1. Initial model of CFA among exogenous constructs

Table 3. Convergent validity values for all constructs

Indicator	Contribution	Construct	Estimate	Notes
X1	<---	Road Pavement	0.772	Valid
X2	<---	Road Pavement	0.930	Valid
X3	<---	Road Pavement	0.425	Invalid
X4	<---	Road Pavement	0.880	Valid
X5	<---	Road Pavement	0.372	Invalid
X6	<---	Road Pavement	0.896	Valid

Indicator	Contribution	Construct	Estimate	Notes
X7	<---	Road Pavement	0.808	Valid
X8	<---	Road Pavement	0.425	Invalid
X9	<---	Road Pavement	0.285	Invalid
X10	<---	Road Pavement	0.845	Valid
X11	<---	Road Pavement	0.859	Valid
X12	<---	Road Pavement	0.453	Invalid
X13	<---	Road Pavement	0.793	Valid
X14	<---	Road Shoulder	0.822	Valid
X15	<---	Road Shoulder	0.928	Valid
X16	<---	Road Shoulder	0.393	Invalid
X17	<---	Road Shoulder	0.873	Valid
X18	<---	Road Shoulder	0.410	Invalid
X19	<---	Road Shoulder	0.842	Valid
X20	<---	Road Shoulder	0.756	Valid
X21	<---	Drainage	0.802	Valid
X22	<---	Drainage	0.824	Valid
X23	<---	Drainage	0.420	Invalid
X24	<---	Drainage	0.841	Valid
X25	<---	Drainage	0.860	Valid
X26	<---	Drainage	0.808	Valid
X27	<---	Road Equipment	0.799	Valid
X28	<---	Road Equipment	0.909	Valid
X29	<---	Road Equipment	0.856	Valid
X30	<---	Road Equipment	0.873	Valid
X31	<---	Road Equipment	0.889	Valid
X32	<---	Road Equipment	0.860	Valid
X33	<---	Complementary Structures	0.963	Valid
X34	<---	Complementary Structures	0.799	Valid
X35	<---	Complementary Structures	0.432	Invalid
X36	<---	Complementary Structures	0.880	Valid
X37	<---	Clearance	0.808	Valid
X38	<---	Clearance	0.830	Valid
X39	<---	Clearance	0.917	Valid
X40	<---	Clearance	0.883	Valid

Notes: <-- means the indicator contributes to the construct

Based on Fig. 1, the results of the CFA among exogenous constructs yielded a chi-square value of 1154.285 with a probability of 0.000 (should be $p \geq 0.05$), indicating that the model is not a good fit. Other fit criteria, such as GFI, RMSEA, and AGFI, also indicate poor fit. Therefore, the convergent validity and some indicators of latent construct need to be reviewed. The loading factor criterion is $\lambda > 0.50$, so if $\lambda < 0.50$, modification or elimination is necessary. The model results show that the convergent validity of some indicators is still below 0.50 (see Table 3), which indicates that these indicators do not significantly contribute to the formation of the exogenous construct. These indicators are eliminated as they do not significantly measure the latent variable. Fig. 2 shows the modified results of the CFA model of the exogenous construct.

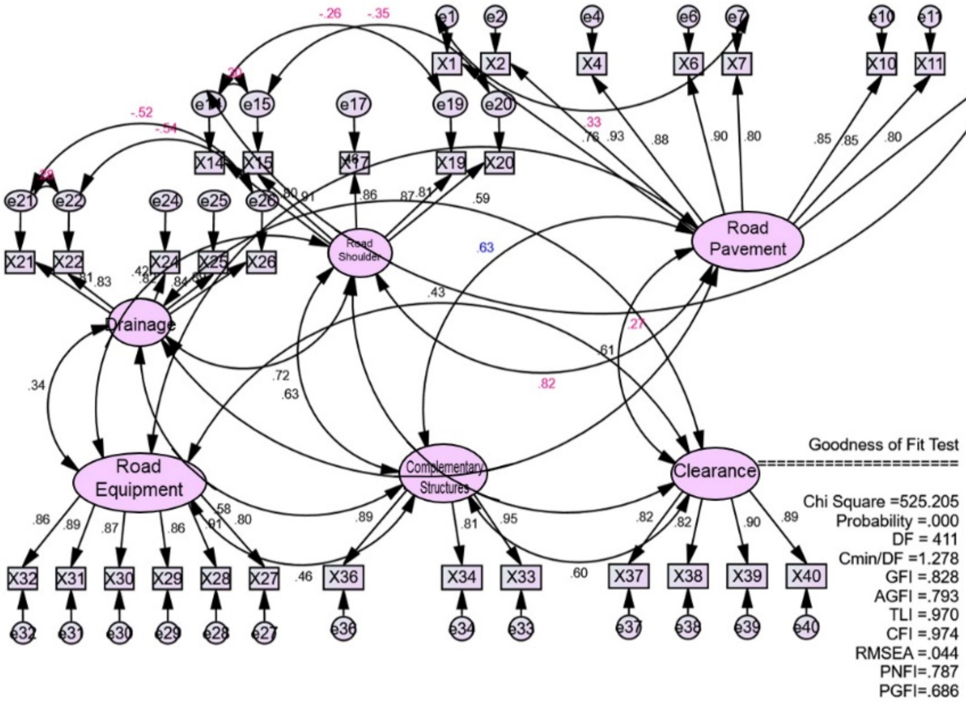

Fig 2. Results of the modified CFA model among exogenous constructs

The model's results in Fig. 2 indicate that the parameter values do not meet the requirements, such as GFI, AGFI, and RMSEA, thus indicating that the model is unfit. The next step to address this issue is to perform CFA on each exogenous factor to obtain several indicators that affect the variables and obtain factor weight values.

3.2 CFA Results for Each Exogenous Construct

The results of CFA for the exogenous construct "road pavement" in stage 1 can be observed in Fig. 3. The CFA analysis results for several GOF requirements still show values indicating that the model is not a good fit. Therefore, the convergent validity values and several indicators for building latent constructs must be reviewed again.

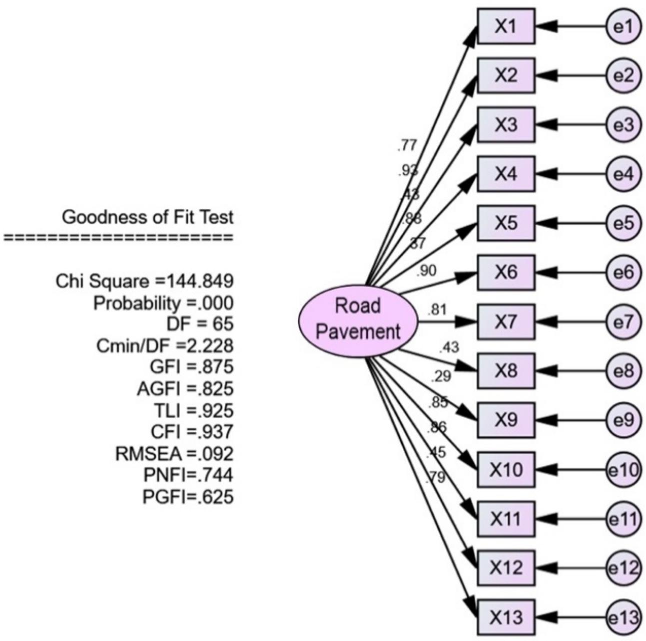

Fig 3. Results of the first-stage CFA for the "road pavement" construct

The model was modified by eliminating several indicators with convergent validity values less than 0.50. Based on Table 3, indicators of the construct "road pavement" have loading factors < 0.50 that must be eliminated, namely indicators X3, X5, X8, X9, and X12. These indicators were eliminated because they did not significantly affect measuring the latent variable.

Table 4. Modification indices values of the "road pavement" construct

Variance			M.I.	Par Change
e10	<-->	e13	4.172	-0.165
e10	<-->	e11	4.636	0.152
e7	<-->	e13	7.300	0.193
e7	<-->	e10	7.110	-0.212
e1	<-->	e10	4.931	-0.172
e1	<-->	e7	15.201	0.267

To obtain a well-fitting structural model, it is necessary to re-estimate the model by examining the modification indices as presented in Table 4. The most significant modification indices (MI) based on Table 4 are 15.201 and 7.300, which are related to the covariance error between "hole, diameter < 10 cm, depth < 4 cm (e1)" and "pavement roughness, IRI < 4 mm/m (e7)", as well as "pavement roughness, IRI < 4 mm/m (e7)" and "uneven patching (e13)". If the model is modified by correlating e1 with e7, the chi-square value can be reduced by at least 15.201.

Statement X1 (potholes, diameter < 10 cm, depth < 4 cm) and X7 (pavement roughness, IRI < 4 mm/m), as well as X13 (uneven patching), are related to the concept proposed by Lin et al. [23] which investigated the correlation between IRI and PCI and found that holes, patching, and rutting have the highest correlation with IRI. Thus it can be concluded that measurement errors of indicators X1 and X7, as well as X7 and X13, can be correlated. Model specification errors in a study can be caused by several factors that cannot be explicitly modeled, so the model specification is not developed ideally based on theory [13]. Cases that occur systematically in two or more latent variables in a model occur because of explicit factors, possibly due to a correlation between measurement error estimations of indicators or error measurement. Re-observation of the questionnaire item raises the suspicion of a correlation between measurement errors of indicators.

The re-observation of the questionnaire item and the examination of the MI values in Table 4 raised suspicion of correlation among the error terms of the indicators, as observed in Table 5. Therefore, it can be concluded that the measurement errors of the indicators in Table 5 can be correlated.

Table 5. Correlation of construction error term for "Road Pavement"

Variances			Statement Item	Concept	Conceptor
e7	<-->	e13	Unevenness of pavement, IRI < 4 mm/m <--> Uneven patching	Distress correlation and IRI	Lin et al. [23]
e1	<-->	e7	Potholes, diameter < 10 cm, depth < 4 cm <--> Unevenness of pavement, IRI < 4 mm/m	Distress correlation and IRI	Lin et al. [23]

From the six constructs analyzed using CFA, only the road equipment and clearance constructs were conducted in one stage because all indicators in this model fit in the first stage of the CFA. Meanwhile, the other constructs, including road pavement, road shoulder, drainage, and complementary structures, must undergo stage 2 CFA after modifying the model. The results of stage 1 CFA for the road equipment and clearance constructs can be seen in Fig.s 7 and 9, respectively. Meanwhile, the stage 2 CFA results for the road pavement, road shoulder, drainage, and complementary structures constructs are presented in Fig.s 4, 5, 6 and 8.

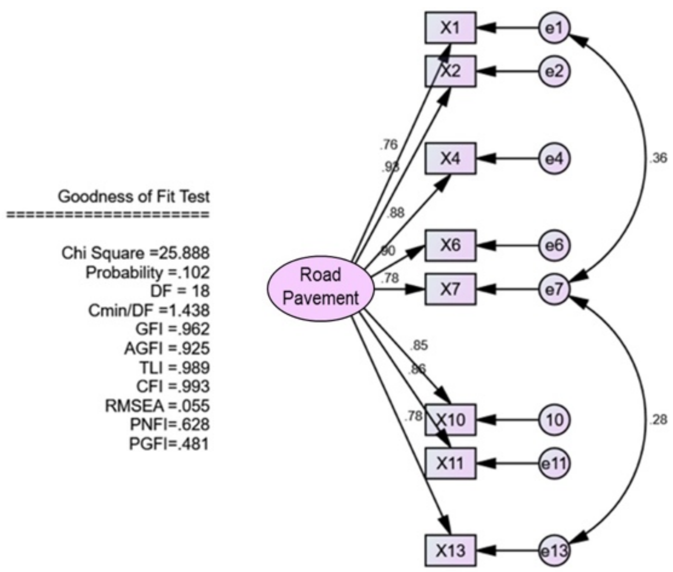

Fig 4. Results of the second-stage CFA for the "road pavement" construct

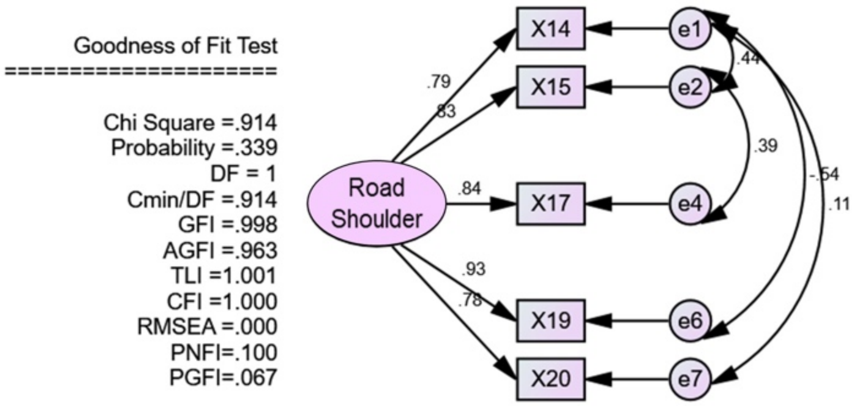

Fig 5. Results of the second-stage CFA for the "road shoulder" construct

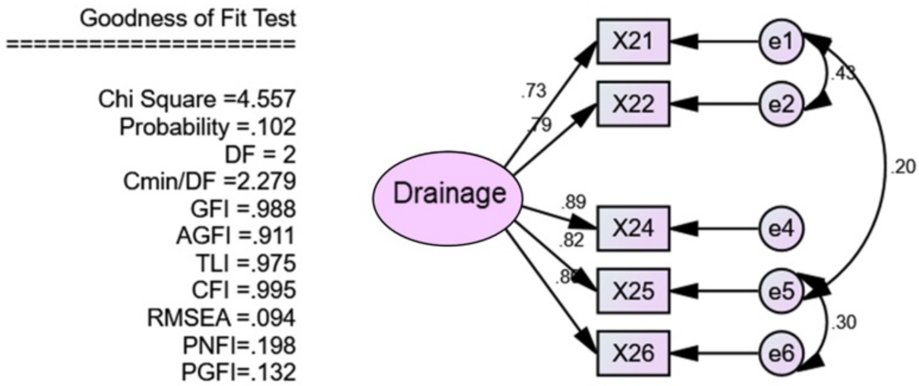

Fig 6. Results of the second-stage CFA for the "drainage" construct

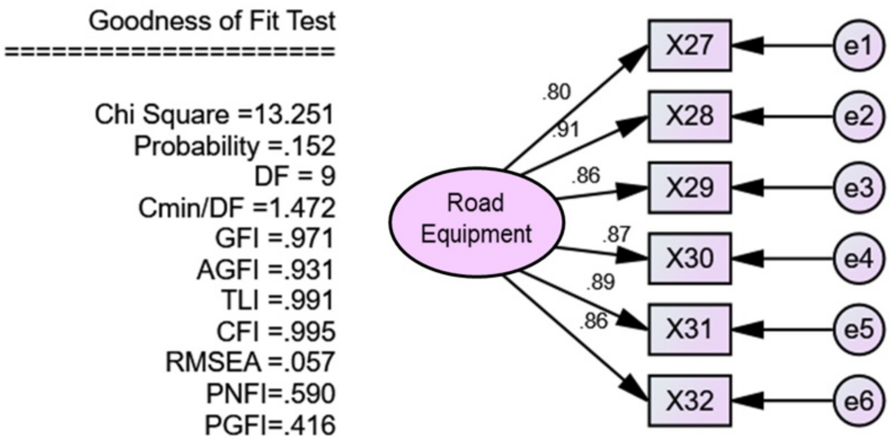

Fig 7. Results of the first-stage CFA for the "road equipment" construct

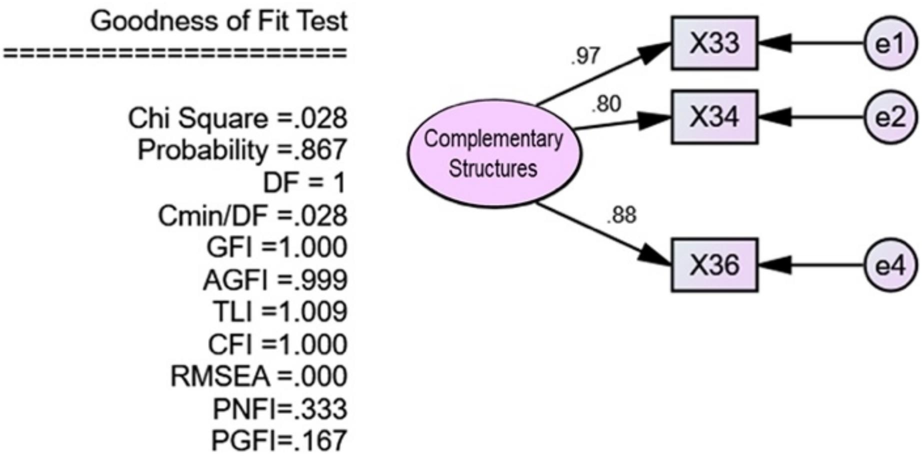

Fig 8. Results of the second-stage CFA for the "complementary structures" construct

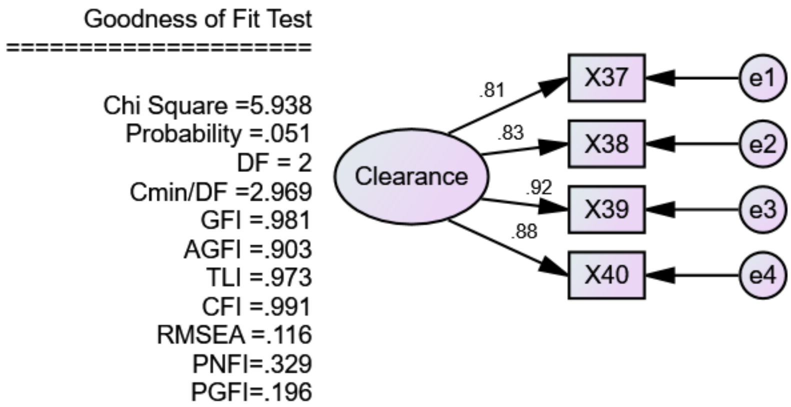

Fig 9. Results of the first-stage CFA for the "clearance" construct

The re-estimation results of the second stage exogenous construct of "road pavement" in Fig. 4 showed that the modified construct produced a chi-square test result of 25.888 with a probability of p = 0.102, indicating that the model is fit. Meanwhile, the re-estimation results of the second stage exogenous construct of "road shoulder" in Fig. 5 produced a chi-square test result of 0.914 with a probability of p = 0.339, indicating that the model is fit. The re-estimation results of the second stage exogenous construct of "drainage" in Fig. 6 showed that the modification of the construct produced a chi-square test result of 4.557 with a probability of p = 0.102, indicating that the model is fit. On the other hand, the first stage CFA results of the exogenous construct of "road equipment" in Fig. 7 were already declared fit from the initial analysis as the convergent validity value for all indicators in this construct was > 0.50 (Table 3). Additionally, the re-estimation results of the second stage exogenous construct of "complementary building" in Fig. 8 showed a chi-square test result of 0.028 with a probability of p = 0.867, indicating that the model is fit. As with the exogenous construct of "road equipment," the CFA test for "clearance" was only conducted at the first stage (Fig. 9) because there were no indicators eliminated, and all convergent validity values were > 0.50.

The other parameter values in the model have met the recommended requirements. The correlation between all observed variables is positive and significant with the formation of latent variables or significantly influences road performance indicators. Some RMSEA values in the CFA test results indicate that they do not meet the criteria, such as in the road shoulder construct (0.000), drainage (0.094), complementary buildings (0.000), and clearance (0.116). In addition, other criteria, such as Cmin/DF for the drainage and clearance constructs, have not met the requirements. Some PGFI criteria are less than 0.50, but in this case, the Parsimonious Fit Measures criterion can be represented by the PNFI value, which meets the requirement of > 0.50 [13]. Additionally, some other Absolute Fit Measures criteria have met the requirements, thus allowing the conclusion that these criteria are acceptable.

The convergent validity values for each modified indicator can be seen in the standardized regression weights presented in Table 6. The results of this CFA conclude that the eliminated indicators were not significantly influential to the road performance indicators. Based on this, the analysis results can provide input for policymakers in the research area to consider and include indicators not yet in the general regulations and evaluate some indicators declared to have no significant impact on fulfilling road performance indicators.

Table 6. Standardized regression weights of indicators for each construct

Indicator	Contribution	Construct	Estimate	Notes
X1	<---	Road Pavement	0.755	Valid
X2	<---	Road Pavement	0.933	Valid
X4	<---	Road Pavement	0.883	Valid
X6	<---	Road Pavement	0.901	Valid
X7	<---	Road Pavement	0.780	Valid
X10	<---	Road Pavement	0.854	Valid
X11	<---	Road Pavement	0.857	Valid
X13	<---	Road Pavement	0.780	Valid
X14	<---	Road Shoulder	0.785	Valid
X15	<---	Road Shoulder	0.834	Valid
X17	<---	Road Shoulder	0.842	Valid
X19	<---	Road Shoulder	0.930	Valid
X20	<---	Road Shoulder	0.775	Valid
X21	<---	Drainage	0.725	Valid
X22	<---	Drainage	0.789	Valid

Indicator	Contribution	Construct	Estimate	Notes
X24	<---	Drainage	0.890	Valid
X25	<---	Drainage	0.820	Valid
X26	<---	Drainage	0.800	Valid
X27	<---	Road Equipment	0.799*	Valid
X28	<---	Road Equipment	0.909*	Valid
X29	<---	Road Equipment	0.856*	Valid
X30	<---	Road Equipment	0.873*	Valid
X31	<---	Road Equipment	0.889*	Valid
X32	<---	Road Equipment	0.860*	Valid
X33	<---	Complementary Structures	0.965	Valid
X34	<---	Complementary Structures	0.798	Valid
X36	<---	Complementary Structures	0.877	Valid
X37	<---	Clearance	0.808*	Valid
X38	<---	Clearance	0.830*	Valid
X39	<---	Clearance	0.917*	Valid
X40	<---	Clearance	0.883*	Valid

Notes: <-- means the indicator contributes to the construct; *the value shown is the same as that obtained in the SEM results before modification because all indicators in these constructs did not undergo elimination process

3.3 Analysis of Response Time for the Fulfillment of Road Performance Indicators

Table 7 shows the response time for road performance indicators based on questionnaire data from service users and providers, literature studies, and the 2018 Revision 2 General Specification of the Ministry of Public Works and Housing [14]. The research results on response time indicate several differences in mode values (the most frequently occurring value) between respondents from service users and service providers. Service providers tend to choose longer response times for repairs than service users. Comparing survey results with literature studies suggests a response time with additional road performance indicators that are more comprehensive than the 2018 Revision 2 General Specification of the Ministry of Public Works and Housing [14].

Table 7. Response time for road performance indicators

Performance Indicators	Response Time (day(s))			
	Service Users (N=71)	Service Providers (N=75)	References	Decision
Road Pavement				
Potholes: Ø <10 cm, depth < 4 cm	< 3	3-7	1 [24], [25]; 2 [26]; 3 [16], [27]; 7 [19]	< 3
Potholes: Ø >10 cm, depth > 4 cm	< 3	3-7	1 [24], [25]; 2 [26]; 3 [16], [27]; 7 [14], [19]	< 3
Cracks: Width > 3 mm, area 5% per 100 m of length	< 7	7-14	-	< 7
Deflection/Depression: Depth > 3 cm, area 5% per 100 m of length	< 7	< 7	7 [14]	< 7
Uneven patching: Not in compliance	3-7	3-7	3 [16], 7 [19], 7-28 [25]	< 7
Pavement Roughness: IRI < 4 mm	< 30	< 30	28 [14]	< 30
Rutting: Depth > 25 mm	< 7	7-14	7 [14], 28 [26], 56 [28], 180 [18]	< 14
Raveling: Any raveling	< 7	7-14	7 [24]; 28 [19], [28]; 30 [16]; 28-56 [25]	< 14
Road Shoulders				
Potholes: Ø < 20 cm, depth < 10 cm	< 3	3-7	7 [16], [24]; 10 [27]; 28-56 [25]	< 7

Performance Indicators	Response Time (day(s))			
	Service Users (N=71)	Service Providers (N=75)	References	Decision
Potholes: Ø > 20 cm, depth > 10 cm	3-7	3-7	7 [14], [16], [24]; 10 [27]; 28-56 [25]	< 7
Elevation: Height difference > 5 cm from the road	7-14	7-14	7 [26], 14 [14], 56 [28]	< 14
Sinkhole: Depth >10 cm, area > 3% per 100 m of length	3-7	3-7	7 [14], [24]; 28-56 [25]	< 7
Ponding: Any ponding	< 3	3-7	28-56 [25]	< 7
Drainage				
Clogging: Clogging in Drainage Channels > 10%	< 7	7-14	1 [24], 3 [27], 7 [14], [16], [18]	< 7
Dirty: Any condition	3-7	3-7	-	< 7
Structural Damage: Any damage	7-14	7-14	7 [26], 21 [14]	< 14
Slope				
Embankment Slopes: Deformation and erosion, as well as poor functionality	7-14	7-14	7 [16], [25]; 14 [14]	< 14
Excavation Slopes: Unstable, weak against erosion, and not functioning properly	7-14	7-14	14 [14]	< 14
Road Equipment				
Warning and Traffic Signs: Not correctly installed according to regulations, structurally weak, and some of the poles are bent	< 7	< 7	21 [14], 24 [26]	< 7
Temporary Signage: Any damage	< 1	< 1	1 [14]	< 1
Median/Sidewalk: Not sturdy and not functioning correctly	7-14	< 7	21 [14]	< 7
Median/Sidewalk: Not visible at night	< 7	< 7	21 [14]	< 7
Guardrail: Not sturdy, not properly installed, and experiencing damage	7-14	14-28	7 [24]–[26], 21 [14]	< 14
Road Markings: Unclear and faded	< 30	< 30	1 [24], 28 [26]	< 30
Complementary Structures				
Access Road or Driveway: Slope > 5 cm	< 7	< 7	14 [14]	< 7
Retaining Wall: Damage to the structure and non-functioning	7-14	7-14	28 [14]	< 14
Retaining Wall: Structural failure resulting in damage to the building structure	2-3	2-3	-	< 3
Clearance				
Wild Vegetation: Height > 10 cm	< 7	< 7	7 [14]	< 7
Cleanliness: Debris, trash, sand/dirt, rubble, or other obstructions	< 7	< 7	1.5 [16], 3-14 [25]	< 7
Illegal Advertisement/Banner: Any condition	< 7	< 7	-	< 7

The proposal of several response time indicators that are not currently included in the general regulations is conducted based on several indicators found in regulations implemented in other countries and those used as references by several international organizations. For example, in Table 7, several road performance indicators that are not listed in the 2018 Revision 2 General Specification of the Ministry of Public Works and Housing [14] include potholes on the road pavement with criteria Ø <10 cm, depth < 4 cm; cracks width > 3 mm, area 5% per 100 m of length; uneven patching; raveling; potholes on road shoulders with criteria Ø < 20 cm, depth < 10 cm; ponding; dirty drainage; retaining wall experienced structural failure resulting in damage to the building structure; cleanliness; and illegal advertisement/banner. The proposed new indicators are based on their urgency in the research area and have been validated in other countries. For instance, in the existing regulations, pothole repairs are required to have a diameter of more than 10 cm and a depth of more than 4 cm. However, in several other countries [16], [19], [24]-[27], more specific criteria are applied, stating that potholes with a diameter less than 10 cm and a depth less than 4 cm must still be repaired within the designated response time. Furthermore, Indonesia is a tropical country with heavy rainfall, making it necessary to consider criteria related to drainage and road surface maintenance to address the effects of frequent rain. Applying specific criteria can be cost-effective, as smaller, proactive repairs may be more economical than addressing larger issues that develop due to neglected maintenance. Additionally, some countries align their criteria with international best practices, as established by organizations like the World Bank, to benefit from global expertise and ensure their road networks meet high-quality standards.

Response time in repairing damaged roads can be influenced by various factors, including infrastructure and supporting facilities, government and bureaucratic systems, resource availability, and government priorities. This is consistent with the data presented in Table 7, which shows variations in response time for the same type of indicator. Countries with good infrastructure and supporting facilities such as easy road access, adequate transportation facilities, and trained human resources will be more capable of quickly repairing damaged roads. In addition, countries with effective and efficient government and bureaucratic systems will be more capable of quickly repairing damaged roads. Conversely, countries with complex bureaucracy and lengthy processes will require more time to respond to and repair damaged roads.

4 CONCLUSION

According to CFA, out of the 40 road performance indicators analyzed, 31 indicators have a significant influence on road performance. Among these indicators, several new ones are proposed to update the regulations stated in the 2018 Revision 2 General Specification of Public Works and Housing of the Republic of Indonesia. This study proposes the inclusion of new road performance indicators, including uneven patching, raveling (aggregate detachment), ponding on the roadside, dirty drainage, unclear and faded markings, litter, sand/soil, debris, or other obstructions, and illegal advertisements/banners. Without the ability to measure and monitor these indicators, road networks may suffer from a range of issues. These include uneven road surfaces causing discomfort and safety risks for drivers, deteriorating road surfaces due to unchecked raveling, and localized flooding and drainage problems as ponding goes unaddressed. Additionally, unclear and faded road markings can lead to confusion and accidents, while dirty roads may affect aesthetics and public perception. Furthermore, unregulated advertisements and banners could obstruct visibility and pose safety hazards.

Additionally, the analysis of response time for these indicators suggests several proposed changes based on respondent feedback and internationally recognized regulations. For instance, concerning the "warning and traffic signs" indicator, the current regulation specifies a response time of 21 days if the signs are not correctly installed according to regulations, structurally weak, and some of the poles are bent. However, the analysis indicates that the response time should ideally be under 7 days.

5 REFERENCES

[1] AASHTO, 2007. Maintenance Manual for Roadways and Bridges. American Association of State Highway and Transportation Officials, Washington DC.

[2] Han, C., Ma, T., Xu, G., Chen, S., Huang, R., 2020. Intelligent decision model of road maintenance based on improved weight random forest algorithm. International Journal of Pavement Engineering, vol. 23, no. 4, 985–997, DOI: 10.1080/10298436.2020.1784418

[3] PIARC (World Road Association), 1994. International Road Maintenance Handbook: Practical Guidelines for Rural Road Maintenance, Volume I of IV (Roadside Areas and Drainage). ODA and TRL, Berkshire.

[4] Sultana, M., Rahman, A., Chowdhury, S., 2013. A review of performance based maintenance of road infrastructure by contracting. International Journal of Productivity and Performance Management, vol. 62, no. 3, 276-292.

[5] Al-Kathairi, A., 2014. Performance Based Road Asset Management System, with a case study: Abu Dhabi [Doctoral dissertation]. Carleton University, Ottawa.

[6] Sultana, M., Rahman, A., Chowdhury, S., 2012. Performance Based Maintenance of Road Infrastructure by Contracting—A Challenge for Developing Countries. Journal of Service Science and Management, vol. 05, no. 02, 118–123, DOI: 10.4236/jssm.2012.52015

[7] Selviaridis, K., Wynstra, F., 2015. Performance-based contracting: a literature review and future research directions. International Journal of Production Research, vol. 53, no. 12, 3505–3540, DOI: 10.1080/00207543.2014.978031

[8] Gajurel, A., 2014. Performance-based contracts for road projects. Springer.

[9] Anastasopoulos, P. Ch., McCullouch, B. G., Gkritza, K., Mannering, F. L., Sinha, K. C., 2010. Cost Savings Analysis of Performance-Based Contracts for Highway Maintenance Operations. Journal of Infrastructure Systems, vol. 16, no. 4, 251–263, DOI: 10.1061/(ASCE)IS.1943-555X.0000012

[10] de la Garza, J. M., Pinero, J. C., Ozbek, M. E., 2009. A Framework for Monitoring Performance-Based Road Maintenance Contracts. Proceedings of the Associated Schools of Construction 45th Annual International Conference, 433–441.

[11] Pataras, M., Kadarsa, E., Susanti, B., Adhitya, B. B., Juliastini, D., 2019. Road Asset Management System Dalam Penanganan Long Segment Jalan Nasional (Studi Kasus: Batas Kota Sekayu–Mangun Jaya). Applicable Innovation of Engineering and Science Research (AVoER), 806–815.

[12] Widhiarso, W., 2009. Praktek Model Persamaan Struktural (SEM) Melalui Program Amos. Universitas Gadjah Mada, Yogyakarta.

[13] Ghozali, I., 2014. Konsep dan Aplikasi Dengan Program AMOS 22. Badan Penerbit Universitas Diponegoro, Semarang.

[14] DJBM, 2020. Spesifikasi umum 2018 untuk pekerjaan konstruksi jalan dan jembatan (revisi 2). Directorate General of Highways of the Republic of Indonesia.

[15] Asian Development Bank, 2018. Guide to Performance-Based Road Maintenance Contracts. Asian Development Bank.

[16] World Bank, 2002. Procurement of Performance-Based Management and Maintenance of roads output Based Service Contract: Sample Bidding document World Bank. World Bank, Washington DC.

[17] Karlaftis, M., Kepaptsoglou, K., 2012. Performance measurement in the road sector: a cross-country review of experience (International Transport Forum Discussion Paper).

[18] Zietlow, G., 2005. Cutting costs and improving quality through performance-based road management and maintenance contracts-the Latin American and OECD experiences (Senior Road Executives Programme).

[19] European Bank, 2016. Policy Challenges in the Implementation of Performance-based Contracting for Road Maintenance (Policy Paper on Infrastructure European Bank for Reconstruction and Development).

[20] Sutradhar, R., Pal, M., 2020. Assessment of Pavement Shoulder Condition in Rural Roads. International Journal on Emerging Technologies, vol. 11, no.1, 91–100.

[21] Zietlow, G., 2002. Using micro-enterprises to create local contracting capacity—The Latin American experience in road maintenance. Senior Road Executives Programme.

[22] Babić, D., Fiolić, M., Babić, D., Gates, T., 2020. Road Markings and Their Impact on Driver Behaviour and Road Safety: A Systematic Review of Current Findings. Journal of Advanced Transportation, vol. 2020, 1–19, DOI: 10.1155/2020/7843743

[23] Lin, J. D., Yau, J. T., Hsiao, L. H., 2003. Correlation analysis between international roughness index (IRI) and pavement distress by neural network. In 82nd Annual Meeting of the Transportation Research Board, vol. 12, no. 16, 1-21.

[24] Silva, M. M., Liautaud, G., 2011. Performance-based road rehabilitation and maintenance contracts (CREMA) in Argentina: a review of fifteen years of experience (1996-2010).

[25] World Bank, 2020. Request for Bids Output and Performance-Based Road Contracts (With or Without Prequalification). The World Bank.

[26] JICA, 2016. Performance Based Road Maintenance Contract (PBC Guideline). Franciscan Kolbe Press, Nairobi.

[27] Stankevich, N., Navaid, Q., Queiroz, C., 2005. Performance-based Contracting for Preservation and Improvement of Road Assets. World Bank Transport Note No. TN-27.

[28] Queiroz, C., 2006. Financing and managing the maintenance and expansion of road networks. In Regional Workshop on public private partnership in highways. World Bank and University of Belgrade.

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