Acta logistica - International Scientific Journal about Logistics
Volume: 11 2024 Issue: 2 Pages: 173-184 ISSN 1339-5629

https://doi.org/10.22306/al.v11i2.495 *Received: 30 Oct. 2023; Revised: 31 Dec. 2023; Accepted: 29 Jan. 2024*

Enhancing road service compliance: a robust penalty model for efficient maintenance management

Tisara Sita
Universitas Gadjah Mada, Faculty of Engineering, Jl. Grafika No. 2, Yogyakarta 55281, Indonesia,
tisarasita@mail.ugm.ac.id
Agus Taufik Mulyono
Universitas Gadjah Mada, Faculty of Engineering, Jl. Grafika No. 2, Yogyakarta 55281, Indonesia,
ataufik.mulyono@ugm.ic.id (corresponding author)
Suryo Hapsoro Tri Utomo
Universitas Gadjah Mada, Faculty of Engineering, Jl. Grafika No. 2, Yogyakarta 55281, Indonesia,
suryohapsoro@ugm.ac.id

Keywords: late penalties, long segment scheme, penalty formula, road preservation, road service level compliance.
Abstract: The long segment scheme allowing contractors to oversee road maintenance still has drawbacks. For example, non-compliance, such as delaying preservation for road issues, persists due to small penalties. This leads service providers to neglect road performance without objection to fines. This research aims to provide sufficient incentives for contractors to comply with the implementation of the late delivery penalty rate of road service levels. This research used an experimental method to test two formulas for the late delivery penalty rate of road service levels on two road sections in Central Java and Special Region of Yogyakarta, Indonesia. During the experiment, the time taken by service providers to fulfill the road service level on the two different road sections was measured and recorded. In the first road section, the previously used formula resulted in a penalty of only $7.39, while the developed formula yielded $122.17. Furthermore, in the second road section, the government formula led to a penalty of $375.89, whereas the developed formula resulted in a fine amount of $1,468.99. The results showed that the penalty value given to contractors for two road segment trials using the research formula was 16 and 4 times higher than the formula used by the Directorate General of Highways. In addition, the developed formula takes into account other road performance indicators such as potholes with a diameter < 10 cm and depth < 4 cm, ponding, and uneven patching.

1 Introduction

Long segment pertains to a preservation effort carried out within the confines of a singular extended stretch, potentially comprising multiple segments, with the objective of establishing a consistent road condition [1,2]. The implementation of road preservation through the long segment scheme in Indonesia has been in effect for over six years (since 2016) [3]. Considering the length of the road, the most essential type of work is road maintenance [4]. Therefore, the handling type is the most important aspect of maintenance activities. The ability of service providers plays a crucial role in carrying out road maintenance activities under the long segment scheme. Service providers must be able to shift from a traditional construction executor to a road segment manager paradigm. This paradigm shift is essential for addressing various flows within logistics, such as material flow, information flow, financial flow, and human flows, thus optimizing the overall management of road segments.

Assessing user satisfaction and project success in road preservation (maintenance, rehabilitation, reconstruction, and widening) from a technical or non-technical aspect is challenging due to the lack of performance indicators. In long segment projects, the entire scope of work is incorporated into one contract, whereas in previous preservation activities, the scope of work is documented in separate contracts. In addition to the quality of work, the implementation of long segment projects must comply with the required road performance indicators. The contractor is obligated to submit weekly reports that compare the road performance indicators with on-site implementation results. The project management or technical management team reviews the weekly reports, and the verification results are used to calculate financial penalties if the road performance indicators are not met. Eventually, if the contractor fails to meet the road performance indicators, they are responsible for paying financial penalties by deducting them from monthly payments.

The quality of road maintenance work in a long segment is one of the indicators of the success of the road pavement plan achievement program. Division 10 of the Directorate General of Highways of the Republic Indonesia requires contractors to meet the road service level based on road performance indicators [5]. The achievement of the road service level is applied to all work achievements within the scope of work, including road pavement, road shoulders, drainage, road equipment, complementary structures, and plant control. If the service provider fails to achieve the road performance indicators according to the specified repair response time, financial penalties in the form of daily payment reduction are

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imposed based on Equation 1 (1). The purpose of applying penalties is to ensure the service provider's obligation to complete the work on time, thereby fulfilling the service users' rights.

$$D = 0.01 \times H \times \frac{Pjc}{Pjl} \times Nlp \quad (1)$$

where,
D: nominal payment reduction,
H: total number of days that the road repair is delayed in meeting the road service level according to the field inspection,
Pjc: the length of the road section that is defective or does not meet the performance indicators in the designated section of the road that has a minimum length of 100 m,
Pjl: the length of the road in the contract according to the scope of work,
Nlp: the contract's work scope value.

Based on the preliminary study results, the financial penalties for delayed road service currently in place are still inadequate [6]. This was evaluated from various indicators, such as response time, traffic volume (vehicles/day), public complaints/reports, length of road that does not meet the road performance indicators per 100 m, and the value of the work scope in the contract. In addition, the amount of the penalty is considered too small, which causes the service providers to neglect the road performance and have no objection to paying the fines. This is evident from the commitment maker officer who imposes penalties for delayed achievement of road performance indicators and the amount of fines imposed is still not significant, as shown in Figure 1.

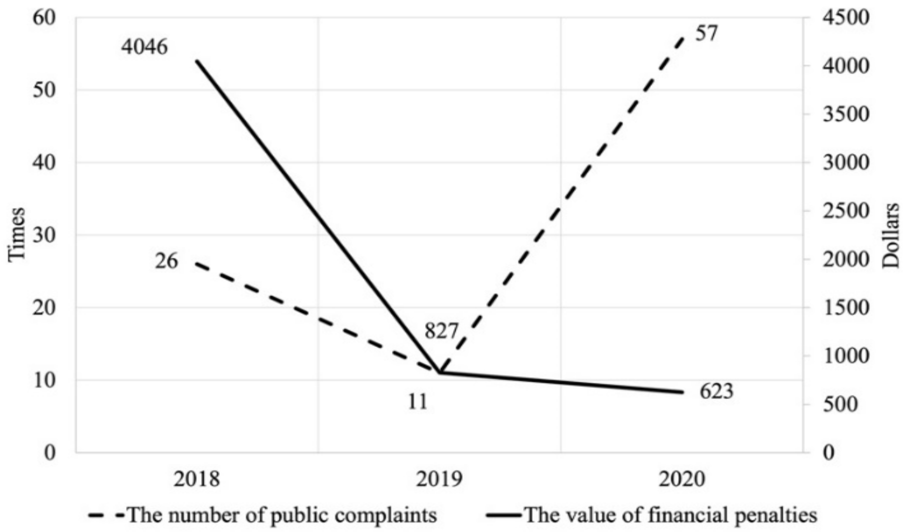

Figure 1 Relationship between public complaints and financial penalties for late fulfilment of road performance indicators in Central Java Region [7]

Service providers are currently neglecting road performance because they believe the penalties are not significant enough. The objective of this research is to address the shortcomings in the current penalty system for delayed road service. Specifically, the study aims to provide sufficient incentives for contractors to comply with the implementation of late delivery penalties through the development of a penalty formula. This formula is designed by considering various elements, with a primary focus on the flow or management of financial resources within the logistics framework. The originality of this research lies in its departure from conventional penalty frameworks for delayed road service. Unlike static systems, this study pioneers a dynamic penalty model that adapts to the nuanced dynamics of road service. Additionally, this research introduces novelty through its experimental approach in specific regions of Indonesia. Rather than relying on established formulas, the study develops and tests a penalty formula for late delivery of road service levels.

2 Literature review

2.1 Road maintenance concept

Road maintenance is the systematic set of activities aimed at preserving and enhancing the safety, quality, and functionality of public roads, with a focus on adapting to changing traffic conditions and evolving economic models [8,9]. Among the types of road maintenance, routine road maintenance is considered essential for preserving the level of road service and road capacity [10]. To implement the road maintenance system precisely and optimally, a road maintenance program with adequate and continuous planning and funding is necessary [11-13]. As noted by Vaitkus et al. [14], the performance of roads declines upon being put into service, intensifying the need for maintenance, particularly due to the significant impact of

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increased traffic volume and climate change on road conditions. Therefore, road maintenance must be conducted by employing several integrated and cost-effective techniques [15,16]. These approaches aim to extend the service life of roads, enhance road safety, and fulfill the needs or desires of road users.

2.2 Penalty regulation

In the context of road maintenance, the application of financial penalties is often intertwined with the concept of performance-based contracts (PBC) [17-19]. PBC are agreements where contractors are held accountable for meeting specific performance indicators and achieving predefined outcomes [20]. Financial penalties serve as a mechanism within these contracts to incentivize compliance and deter deviations from agreed-upon standards. The occurrence of penalties in road maintenance contracts is typically linked to the failure of contractors to meet specified performance indicators within the stipulated repair response times. This aligns with the performance-based nature of the contract, where the focus is on achieving desired outcomes, such as road quality and timely repairs.

In PBC in Argentina, payments are not based on the unit price for each individual work item, but rather on the contractor's compliance with predetermined quality standards and specified outcomes [21]. This system permits the implementation of penalties or financial penalties if the desired quality or level of service is not met. The application of agreed-upon penalties or financial sanctions must be enforced in the event of contractor non-compliance with road performance indicators. According to the Asian Development Bank [22], if the contractor fails to remedy defective road conditions in a timely manner, automatic payment reductions will be implemented and will increase significantly in subsequent periods if the deficiency is not rectified. This system has been implemented in Ukraine, where the contractor must pay penalties in the form of greater payment reductions for failing to detect non-compliance if service users identify additional defects not included in the system. Additionally, it was found that there are concerns regarding the stringent enforcement of penalties in the Philippines, and the penalties applied under the PBC are relatively moderate. To increase the efficiency of PBC as a road service mechanism, it is recommended that the financial penalties for failing to meet road service levels are rigorously enforced. For non-compliance with performance standards, the expression "payment reduction" is used because the term "penalties" is not well received among contractors. The value of payment reduction must be sufficient to provide contractors with sufficient incentives to conform. If the payment reduction is insufficient, contractors tend to be less compliant; if it is excessive, contractors may add risk premiums to their bid prices. Therefore, it is essential to accurately determine the appropriate payment reduction for each instance of non-compliance.

In the following subsections, several references are presented regarding penalties or payment reductions implemented in various countries. This serves as consideration for implementation in Indonesia or for reviewing existing regulations in Indonesia operating under the long segment scheme.

2.2.1 Penalty framework in Argentine PBC

According to Silva and Liautaud [23], performance indicators should be as minimal and straightforward as feasible to facilitate observation and evaluation. Throughout the duration of the contract, the rehabilitation bundle for road thickness, maximum roughness level, groove depth, cracks, and raveling must conform to the specifications. For example, compliance with specifications entails the absence of visible potholes or exposed cracks, the absence of excessive wheel marks, and the maintenance of good conditions on shoulders, culverts, drainage channels, guardrails, vertical and horizontal signs, and the overall road environment. For each component, penalties for non-compliance are established and enforced to discourage contractors from failing to comply. For example, if a pothole is not addressed within the specified timeframe, the service provider will incur a fine of approximately $1,200 per day until the repair is completed (as indicated in Table 1). The total amount of penalties imposed is then subtracted from the monthly payment.

Table 1 Penalties for late fulfilment in road performance criteria in Argentina

Parameter	Fulfilment Conditions	Penalties (USD)
Rehabilitation		
Pavement roughness	IRImax = 3 (Asphalt Concrete/AC) IRImax = 3.5 (ST/RC)	600/week/km
Pavement rut depth	Maximum 1 cm	1,200/week/km
Pavement edge reduction	0 cm	1,200/week/segment
Pothole diameter > 2.5 cm	100% patched	1,200/pothole/day
Cracking	100% closed	600/week/km
Concrete pavement joint cracks	100% closed	600/week/km
Raveling	0%, and < 2% if road maintenance	600/week/km
Routine Maintenance		

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Parameter	Fulfilment Conditions	Penalties (USD)
Uneven road	Maximum 3 cm	1,200/week/ segment
Cracking	100% closed for type 4	600/week/km
Pothole	100% patched	1,200/pothole/km
Raveling	100% pathced	600/week/km
Shoulder hardened	Pothole/raveling = 0 Shoulder drop = 0 Rutting < 12 mm Cracking closed (100%)	1,200/week/km
Shoulder not hardened	There is no erosion, no channeling, and good cross slope; edge drop < 2 cm; width ≥ 3 m	1,200/week/km
Roadside vegetation/brush clearing	Brush height < 15 cm of 15 m	1,200/week/km
Cleaning box culverts/drainage/bridge	Clean/no clogging	600/day/km
Right-of-way area cleaning	No dirt, green area maintenance	600/day/km
Sign	Preserved, clearly visible during both day and night	150/day/sign
Lightning	Preserved	150/day/lamp
Road markings	Preserved, clearly visible during both day and night	300/day/line/km
Guardrail	Good condition	1,200/week/location

Source: [23]

2.2.2 Penalty framework in CAREC member countries' PBC

As per the Central Asia Regional Economic Cooperation (CAREC), not meeting road performance indicators will lead to payment reductions. This includes scenarios where reports are not processed within the specified timeframe, the average roughness of a road section surpasses the specification, or potholes exceed the maximum size. Payment deductions are determined in local currency or as a percentage of the total monthly flat sum payment per km. When service users discover non-compliance, payment reductions are implemented, and additional payment reductions are implemented when damage is not repaired within a predetermined timeframe. If response times have been routinely missed, payment reductions may increase. Table 2 provides an example of the application of payment reductions in CAREC member countries.

*Table 2 Example of reduction in payment for failure to meet road performance indicators in CAREC member countries**

Criteria	Performance Level	Reduced payment on first inspection	Reduced payment for follow-up inspection
		(% of monthly lumpsum/km)	
Pothole on the road surface	The pothole shall not be wider than 10 cm from any direction.	5% for every 1 km of road section with potholes	15% for every 1 km of road section that has potholes until the potholes are fixed
Rutting	Depth of groove does not exceed 20 mm with a length of 3 m, every 100 m.	10% every 100 meters that do not meet the criteria	20% on every 100 meters that do not meet the criteria until rutting is addressed
Vertical sign	One or more traffic signs are not damaged, unreadable, misplaced, or not functioning.	5%	10% until the sign is repaired or replaced
Vegetation	The maximum vegetation height measured anywhere within a 100-meter stretch is above the threshold value limit.	5% every 100 m	10% for every 100 meters until vegetation is cut to the allowed height

Note: *CAREC countries: Afghanistan, Azerbaijan, China, Georgia, Kazakhstan, Kyrgyz Republic, Mongolia, Pakistan, Tajikistan, Turkmenistan, and Uzbekistan.
Source: [22]

2.2.3 Penalty framework in World Bank-funded projects' PBC

According to the World Bank [24], payment reductions are applied for failure to meet road performance level requirements. The results of road performance level inspections and criteria are documented in a memorandum, which includes the categories and locations of non-compliance, especially those listed in the standard table

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included in the service provider's monthly report. Each instance of non-compliance will be assigned a correction deadline. Therefore, site visits are required on the specified dates to confirm that the contractor has addressed the road performance level non-compliance findings. If the contractor has not corrected the non-compliance by the deadline specified in the memorandum, payment reductions will be imposed. Service providers who fail to remedy the cause of previously applied payment reductions will see the amount of reduction increase from month to month, without limit, until the road performance level is achieved. The initial payment reduction calculation for the first month ranges from 10% to 50% of the monthly lump sum, depending on the type of road components [19]. Meanwhile, late handover beyond 30 days is determined by Equation 2 (2).

$$PR = 2^n PR_u \quad (2)$$

Where>

PR: payment reduction, which is the reduction in payment calculated if non-compliance is not rectified within 30 days,

$n = \frac{J-1}{30}$ (n is rounded to the nearest whole number, without decimals),

J: the number of days of non-compliance,

PR_u: the unit rate for payment reduction, which applies during the first 30 days of non-compliance.

3 Methodology

This research utilized an experimental method to test the formula for road service delay penalties. Two formulas were tested on two road segments managed by the National Road Implementation Center of Central Java and Special Region of Yogyakarta, Indonesia. The first formula was the one used by the Directorate General of Highways since 2020, while the second formula was developed in this study. Initially, the study identified the needs and conducted a literature analysis related to the penalty for road service delay. To capture survey data, questionnaires are distributed to a sample of respondents in order to collect primary data. There are two options for completing questionnaires: printed copies or *Google Forms*. Indicators for each factor that contributes to penalties for late fulfillment in road service level were used to develop the questionnaires. The new formula was tested on two different road segments with varying conditions. During the experimental stage, the time taken to fulfill the road service level by the contractor/service provider was measured and recorded for the two road sections. The results obtained were then calculated using the two formulas mentioned earlier, which led to the determination of the penalties for both road sections.

4 Result and discussion

4.1 *The developed penalty formula*

The current formula for calculating penalties only considers a limited set of factors, including the duration of the delay, the length of the defective road segment, the length of the road under contract, and the value of the scope of work. In this study, a mathematical model was developed to provide a more comprehensive framework for calculating penalties for late fulfillment of road service levels. This model is based on the idea that formulas represent a physical representation of mathematical concepts and can be used to understand the correlation between different variables in an intuitive and straightforward way. To validate the model, tests were conducted on two road sections in Central Java and Special Region of Yogyakarta, which revealed valuable insights into the nature and extent of the errors that may arise when using the formula. Equation 3 was derived as the formula for calculating penalties for late fulfillment in road service levels.

$$S = Koef \ x \ T \ x \ F_V \ x \ N \ x \ F_A \ x \ J \quad (3)$$

Where:

S: the amount of financial penalty for failing to meet the road service level,

Koef: the coefficient value for each road component, as shown in Table 3,

T: the delay in responding to road performance in days,

F_V: the traffic volume factor, where Primary Arterial Roads (PAR) has a factor of 1 and Primary Collector Roads-1 (PCR-1) has a factor of 0.9,

N: the multiplier value for the penalty/cost of routine road maintenance,

F_A: the community complaint factor, where no complaints have a factor of 1, verified complaints by National Road Implementation Center or National Road Service have a factor of 1.5, and accidents have a factor of 2,

J: the length of the road that fails to meet the criteria, which is determined by dividing the length of the faulty or poor-performing road segment (minimum length of 100 m) by the length of the road covered in the contract.

Table 3 Factor score weight

Component	Factor score weight (*Koef*)
Road Pavement	0.027
Road Shoulder	0.020
Drainage	0.011
Road Equipment	0.001
Complementary Structures	0.006
Clearance	0.017

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4.1.1 Coefficient variable (*Koef*)

The coefficient in the formula currently applied to the long segment scheme is 0.01 for all types of road damage. Meanwhile, the formula resulting from this study applies different coefficient values for each road component (see Table 3). These coefficient values are derived from factor score weights obtained during the analysis, representing the intercorrelation between manifest and latent variables. The final model produces a set of factor score weights, serving as regression coefficient estimates for predicting latent variables based on observed variables. The term "factor score weight" denotes the proportional influence of variable X on variable Y—when X changes, it proportionally impacts Y. The initial coefficient value (*Koef*) of 0.01 undergoes variation for different types of damage influencing the penalty value. For instance, the coefficient acting as a multiplier for road pavement damage (such as potholes) is 0.027, surpassing other components like clearance (road cleanliness, etc.), which carries a value of 0.017.

4.1.2 Variable *T* (delayed response time)

In this study, the response time for each type of road performance indicator damage considered in the delayed penalty formula is outlined in Table 4. Each day of delay is factored into the formula as a multiplier. For instance, if a pothole is repaired within 9 days of discovery, based on Table 4, it should be fixed within a maximum of 3 days, resulting in a 6-day delay. Therefore, the value of *T* in the formula is 6.

Table 4 Response times for road performance indicators

Components	Conditions	Response Time
Road Pavement		
Potholes	Any pothole	< 3 days
Cracks	Width > 3 mm, area 5% per 100 m of length	< 7 days
Deflection/Depression	Depth > 3 cm, area 5% per 100 m of length	< 7 days
Uneven patching	Not in compliance	< 7 days
Pavement roughness	IRI > 4 mm	< 30 days
Rutting	Depth > 3 cm	< 14 days
Raveling	Any raveling	< 14 days
Road Shoulders		
Potholes	Any potholes	< 7 days
Elevation	Height difference > 5 cm from the road	< 14 days
Sinkhole	Depth >10 cm, area > 3% per 100 m of length	< 7 days
Ponding	Any ponding	< 7 days
Drainage		
Clogging	Clogging in drainage channels > 10%	< 7 days
Dirty	Dirty	< 7 days
Structural damage	Damage	< 14 days
Embankment slopes	Deformation and erosion, as well as poor functionality	< 14 days
Excavation slopes	Unstable, weak against erosion, and not functioning properly	< 14 days
Road Equipment		
Warning and traffic signs	Not correctly installed according to regulations, structurally weak, and some of the poles are bent	< 7 days
Temporary signage	Unrepaired road damage	≤ 24 days
Median/sidewalk	Not sturdy, not functioning correctly, or not visible at night	< 7 days
Guardrail	Not sturdy, not properly installed, and experiencing damage	< 14 days
Road markings	Unclear and faded	< 30 days
Complementary Structures		
Access road or driveway	Slope > 5 cm	< 7 days
Retaining wall	Damaged, cracked, or broken	< 14 days
Clearance		
Wild vegetation	Height > 10 cm	< 7 days
Cleanliness	Debris, trash, sand/dirt, rubble, or other obstructions	< 7 days
Illegal advertisement/banner	Illegal advertisement/banner	< 7 days

Source: Survey results.

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4.1.3 Traffic volume factor (F_v)

The traffic volume factor (F_v) is determined based on secondary data on the average annual daily traffic (AADT) volume on the road section under review. Road damage on a section with high AADT has a greater impact on road users compared to a section with lower AADT [25]. Retallack and Ostendorf [26] stated that the frequency of accidents increases with higher traffic volumes. The accident rate gradually increases with the increase in traffic volume until around 11,000-13,000 vehicles/day on a two-lane road. At this limit, traffic flow instability conditions are prone to occur, such as lower driving speeds and limited maneuvering space, which leads to a higher risk of accidents [27,28].

The relationship between the number of traffic accidents and AADT is not entirely linear but shows an exponential relationship [29]. The pavement condition is one of the main factors contributing to accidents [30-32]. Li et al. [33] stated that poor pavement conditions are proportionally associated with more severe accidents, but very poor pavement conditions are associated with less severe accidents. Excellent pavement conditions may lead to high-speed driving behavior and result in more severe accidents. The severity of accidents can be reduced if the pavement condition is maintained in good condition [34].

Road classification based on AADT is shown in Table 5. As road classification varies and there is currently no road classification based on traffic volume in Indonesian regulations, guidelines, or literature, the traffic volume factor (F_v) based on road classification in the National Road Decision is used.

Table 5 Classification of roads based on average annual daily traffic (AADT)

Classification	AADT
Low	30,000-60,000
Moderate	60,000-100,000
Moderate-High	100,000-200,000
High	> 200,000

Source: [35]

The classification of roads is determined by their function, categorized as arterial, collector, and local. Additionally, roads are classified based on the road system into primary and secondary. Based on the Minister of Public Works and Housing Decree Number 430/KPTS/M/2022 regarding the Designation of Road Segments, in according to their function, roads can be categorized as Primary Arterial Roads (PAR) and Primary Collector Roads-1 (PCR-1). The differences between PAR and PCR-1 are shown in Table 6. The traffic volume factor (F_v) is determined based on Table 6 with the classification of PAR and PCR-1 roads. From the survey results, F_v for PAR is determined to be 1.0, while F_V for PCR-1 is 0.9.

Table 6 Comparison of Primary Arterial Roads (PAR) and Primary Collector Roads-1 (PCR-1)

Classification	PAR	PCR-1
Connectivity	Among NAC, NAC with RAC	NAC with LAC, among RAC, RAC with LAC
Distance	Long distance, should not be disrupted by bi-directional traffic, local traffic, and local activities	Medium distance
Planned Speed	Min. 60 km/hour	Min. 40 km/hour
Capacity	Greater than its average traffic volume	Greater than its average traffic volume
Road width	Min. 11 m	Min. 9 m

Notes: NAC = National Activity Center; RAC = Regional Activity Center; LAC = Local Activity Center.
Source: [5]

4.1.4 Penalty multiplier factor (N)

The penalty multiplier factor (N) is established as the basis for the proposed formula calculation. The analysis shows that the penalty multiplier factor (N) used is the value of the self-estimated cost for routine work. This value is chosen because each service provider/contractor can bid on low-scope routine work, resulting in a low contract value for routine work. The 2018 Revision 2 General Specification for Road Construction imposes penalties for delays in meeting the road service level based on the value of the contract's work scope. Based on the analysis results, the penalty multiplier factor in the formula resulting from this study is the value of the routine work scope in the contract, in accordance with this regulation.

4.1.5 Public complaints factor (F_A)

The public complaints factor (F_A) was also established as the basis for the proposed formula calculation. The research results show that the types of complaints considered in the penalty formula calculation are those that have been verified by the National Road Implementation Center. Reports or complaints are gathered through various channels, including social media platforms (*Instagram*, *Facebook*, and *Twitter*), letters or email, *www.lapor.go.id*, Command Center *Bina Marga*, direct visits, and other mediums such as *WhatsApp*, *LaporGub*, *Jalan Cantik*, and other channels. The survey results indicate that a penalty multiplier of 1.5 times should be applied in the case of a complaint regarding road performance, and a penalty

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multiplier of 2 times should be applied in the event of an accident caused by road damage.

4.1.6 Substandard road length (J)

The formula developed in this study considers the factor of road length that does not meet the criteria (J). Based on the literature review and analysis results, the penalty multiplier value in the developed formula is determined by dividing the length of any segment of at least 100 m of defective road (not meeting performance indicators) by the total road length (m) specified in the contract based on the scope of work. This calculation adheres to the guidelines provided by the Directorate General of Highways.

4.2 Trial of penalties model

4.2.1 Model trial on roads with short routine scope

The Keprekan-Muntilan-Salam road preservation package is a long segment package with a total contract value of $4,127,381. This package's scope of work encompasses standard enlargement, preservation reconstruction, road rehabilitation, routine road preservation, routine condition maintenance, holding, bridge preservation, and routine bridge preservation. Routine road preservation, routine condition maintenance, and holding are included in the management scope of the road performance indicators. These domains are subject to monetary penalties for failure to meet road service levels on time, with the following data breakdown:

- Self-estimated cost of routine scope (N or Nlp): $6.340.
- Length of routine scope: 3,430 m.
- Function and road system: Primary Arterial Road (PAR).
- Road Segments: Keprekan-Muntilan City Border; Muntilan-Salam (Boundary of the Special Region of Yogyakarta).

Table 7 Determination of penalty values for the preservation package of Keprekan-Muntilan-Salam road using the formula from the research results

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	T (days)	F_V	F_A	J	S ($)
Road Pavement	Pothole, diameter < 10 cm and depth < 4 cm	Keprekan-Muntilan City Border	3	10	0.027	7	1	1.0	0.029	34.93
	Uneven patching	Keprekan-Muntilan City Border	7	11	0.027	4	1	1.0	0.029	19.96
	Pothole, diameter > 10 cm and depth > 4 cm	Muntilan- Salam	3	11	0.027	8	1	1.5	0.029	59.88
Road Shoulder	Ponding	Muntilan-Salam	7	9	0.020	2	1	1.0	0.029	7.39
Total										122.17

Notes: Exchange rate $1 = Rp15,902; Response time used is from Table 4; T or late is calculated by subtracting actual response time with response time; F_v for PAR is 1; F_A is 1 since there was no public complaints regarding this damage; J is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (3,430 m); N = $6.340.

Table 8 Determination of penalty values for the preservation package of Keprekan-Muntilan-Salam road using the formula from the Directorate General of Highways

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	H (days)	Pjc/Pjl	D ($)
Road Pavement	Pothole, diameter < 10 cm and depth < 4 cm	Keprekan-Muntilan City Border	NA	NA	NA	NA	NA	NA
	Uneven patching	Keprekan-Muntilan City Border	NA	NA	NA	NA	NA	NA
	Pothole, diameter > 10 cm and depth > 4 cm	Muntilan-Salam	7	11	0.010	4	0.029	7.39
Road Shoulder	Ponding	Muntilan-Salam	NA	NA	NA	NA	NA	NA
Total								7.39

Notes: Exchange rate $1 = Rp15,902; Response time used is adopted from the 2018 Revision 2 General Specification for Road Construction; Response time with NA (not applicable) means that the type of damage is not listed in the regulation, and therefore, the service providers are not obligated to perform any maintenance; H is calculated by subtracting actual response time with response time; Pjc/Pjl is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (3,430 m); Nlp = $6.340.

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4.2.2 Model trial on roads with long routine scope

The preservation and rehabilitation package for the Sruwen-Kartosuro-Klaten-Prambanan road is a long-segment project with a total value of $6,554,918. This programme entails widening to standard width, road rehabilitation, routine road maintenance, periodic bridge maintenance, and routine bridge maintenance. Routine road maintenance is included in the road performance indicator's scope of management. This scope is subject to financial penalties for failing to satisfy the road service level on time, as outlined below:

- Self-estimated cost of routine scope: $1,026,486.389.
- Length of routine scope handling: 68,270 m.
- Road function and system: Primary Arterial Road (PAR).
- Road segments: a. Sruwen-Boyolali Terminal; b. Pandanaran II Boyolali; c. Pandanaran I Boyolali; d. Perintis Kemerdekaan/Southern Ring Road Boyolali; e. Boyolali City Border -Kartosuro; f. Kartosuro-Klaten City Border; g. Perintis Kemerdekaan Klaten; h. Diponegoro Klaten; i. Kartini Klaten; j. Suradji Klaten; k. Klaten City Border-Prambanan.

Table 9 Determination of penalty values in for preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road using the formula from the research results

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	T (days)	F_V	F_A	J	S ($)
Road Pavement	Pothole, diameter > 10 cm and depth > 4 cm	Klaten City Border-Prambanan	3	10	0.027	7	1	2.0	0.001	568.35
Road Shoulder	Pothole, diameter < 20 cm and depth < 10 cm	Sruwen-Boyolali Terminal	7	9	0.020	2	1	1.0	0.001	60.14
	Ponding	Kartosuro-Klaten City Border	7	9	0.020	2	1	1.0	0.001	60.14
Drainage	Clogging	Southern Ring Road Boyolali	7	9	0.011	2	1	1.0	0.003	66.16
	Structural damage	Boyolali City Border-Kartosuro	14	19	0.011	5	1	1.0	0.004	248.09
Road Equipment	Damaged median	Kartosuro-Klaten City Border	7	11	0.001	4	1	1.0	0.001	6.01
Clearance	Wild vegetation	Diponegoro Klaten	7	10	0.017	3	1	1.0	0.009	460.09
Total										1,468.99

Notes: Response time used is from Table 4; T is calculated by subtracting actual response time with response time; F_V for Primary Arterial Road is 1; F_A is 1 since there was no public complaints regarding this damage; J is calculated by dividing 100 m (which represents the minimum number of road defects) by the length of road specified in the contract (68,270 m). However, for drainage clogging and structural damage and clearance, J is calculated by dividing 200, 300, and 600 m, respectively, by the length of road in the contract; N = $1,026,486.389.

Table 10 Determination of penalty values in for preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road using the formula from the Directorate General of Highways

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	H (days)	Pjc/Pjl	D ($)
Road Pavement	Pothole, diameter > 10 cm and depth > 4 cm	Klaten City Border-Prambanan	7	10	0.010	3	0.001	45.11
Road Shoulder	Pothole, diameter < 20 cm and depth < 10 cm	Sruwen-Boyolali Terminal	NA	NA	NA	NA	NA	NA
	Ponding	Kartosuro-Klaten City Border	NA	NA	NA	NA	NA	NA
Drainage	Clogging	Southern Ring Road Boyolali	7	9	0.010	2	0.003	60.14
	Structural damage	Boyolali City Border-Kartosuro	21	19	0.010	In compliance	0.004	0
Road Equipment	Damaged median	Kartosuro-Klaten City Border	21	11	0.010	In compliance	0.001	0
Clearance	Wild vegetation	Diponegoro Klaten	7	10	0.010	3	0.009	270.64
Total								375.89

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Notes: Response time used is adopted from the 2018 Revision 2 General Specification for Road Construction; Response time with NA (not applicable) means that the type of damage is not listed in the regulation, and therefore, the service providers are not obligated to perform any maintenance; H is calculated by subtracting actual response time with response time; Pjc/Pjl is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (68,270 m). However, for drainage clogging and structural damage and clearance, Pjc/Pjl is calculated by dividing 200, 300, and 600 m, respectively, by the length of road in the contract; Nlp = $1,026,486.389.

The penalty value for delays in meeting road service levels for the preservation package of Keprekan-Muntilan-Salam road (short routine scope) is 16 times higher when using the formula derived from this study (Table 7) compared to the formula from the Directorate General of Highways (Table 8). In the case of the preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road (long routine scope), the formula derived from this research (Table 9) resulted in a penalty value that was nearly 4 times greater than the formula from the Directorate General of Highways (Table 10). The difference in results between the two formulas occurs because, in addition to the impact of variables included in the formula, the proposed formula introduces new indicators for penalty consideration. For instance, the trial includes factors such as potholes with a diameter less than 20 cm and depth less than 10 cm, uneven patching, and ponding. Additionally, the proposed formula also employs the suggested response time for enhancing road performance.

4.3 Implication and application

The newly developed penalty formula introduces a significant advancement in ensuring road quality. It surpasses conventional methods of penalty calculation, providing a more sophisticated system. This modification has the potential to substantially impact how penalties operate and enhance the understanding of how companies manage roads. In regions where companies oversee road maintenance, challenges arise. Companies sometimes neglect rules and delay road repairs. The existing fines for these delays are minimal, often overlooked by companies. The formula acts as a tool to incentivize companies to comply with rules and improve road maintenance. The formula is not just theoretical; it can be applied in practical situations. It integrates smoothly into existing decision-making systems for road service, offering various benefits such as ensuring fair fines and holding companies accountable for their responsibilities. Its adaptability makes it a valuable tool for enforcing rules in different scenarios. However, it is crucial to acknowledge that the formula is not flawless. Its effectiveness may be influenced by the availability and quality of data, especially in regions where data collection is challenging. Additionally, it may not perform optimally in all road situations, as unforeseen variables could impact its predictive accuracy. Continuous refinement is necessary to enhance its practical utility and reliability in real-world enforcement scenarios.

5 Conclusions

This research successfully developed a new penalty formula for non-compliance in meeting road service levels applied to road service providers. This formula includes additional indicators such as coefficients for each road component based on their significance, proposed improved response time, traffic volume factor, and community complaint factor. In addition to these factors, the financial flow of the penalty system plays a crucial role. The results of the formula trial on two road sections yielded values that were 16 and 4 times higher than the fines resulting from the formula used by the Directorate General of Highways. These relatively high penalties are in line with the Asian Development Bank recommendation that payment deductions (in this case, penalties) should be sufficiently high to provide adequate incentives for contractors to comply. If payment deductions are too low, contractors are likely to be less compliant, while if they are too high, contractors will apply risk premiums to their tender prices. In contracts that apply financial penalties for each failure to meet road service levels, contractors/service providers strive to continuously improve performance while reducing costs. However, experience has shown that payment deductions are often not strictly enforced by the Asian Development Bank, including in Indonesia, so strict enforcement of penalties for delayed delivery of road service levels is necessary.

It is recommended to conduct further research related to the value of reducing payment penalties in road maintenance contracts in Indonesia. Future investigations should delve into the impact of strict penalty enforcement on contractor behavior and overall project outcomes, assessing whether heightened penalties lead to sustained improvements in road infrastructure quality. In addition, a comparative analysis of penalty systems in road maintenance contracts across different countries could uncover best practices adaptable to the Indonesian context. Furthermore, researchers should examine the role of effective stakeholder collaboration and communication in ensuring the successful implementation of penalty systems. The research should culminate in specific policy recommendations for enforcement agencies, offering guidelines for the monitoring, evaluation, and adaptation of penalty structures to enhance their effectiveness and fairness over time. Finally, long-term monitoring of road conditions and an assessment of public perception and community impact would contribute to a comprehensive understanding of the ramifications of such penalty structures.

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Single-blind peer review process.

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