ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

Optimal Maintenance Strategy for the Palu–Kulawi Road Section Based on Life Cycle Cost Analysis (LCCA) (Case Study: Guru Tua Road)

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Publication Date: 2026/03/28

Abstract: Roads constitute an essential infrastructure that supports mobility and regional development. As the service life increases and traffic loads intensify, road performance may deteriorate, thereby affecting traffic flow and the level of service. This study aims to determine the current condition of the pavement on Guru Tua Road along the Palu–Kulawi road section through an assessment using the Pavement Condition Index (PCI) method, identify alternative road maintenance strategies basedS on the PCI value of each sample unit, analyze the life cycle cost (LCCA) for each maintenance strategy alternative on Guru Tua Road along the Palu–Kulawi section, and recommend an optimal maintenance strategy that aligns with the road condition and cost efficiency over the design life. Data were collected through road condition surveys and planning data, which were subsequently analyzed using the Pavement Condition Index (PCI) method to determine the road condition classification. Furthermore, the Life Cycle Cost Analysis (LCCA) method was employed to evaluate alternative maintenance strategies. The results of the Pavement Condition Index (PCI) evaluation indicate that Segment 1 (Km 0+000–1+300) has an average PCI value of 78.88 and Segment 2 (Km 1+300–2+600) has an average PCI value of 75.43, both categorized as fair condition, thus periodic maintenance Sis recommended. Segment 3 (Km 2+600–3+900) has an average PCI value of 68.45, which falls into the poor condition category, therefore rehabilitation measures are required. For each segment, three treatment alternatives were developed and subsequently analyzed using the Life Cycle Cost Analysis (LCCA) method. In Alternative 1, the Equivalent Uniform Annual Cost (EUAC) at a discount rate of 8% with a Capital Recovery Factor (CRF) of 0.102 shows that Alternative 1 has a Present Value (PV) of IDR 13,655,411,431, with an Equivalent Uniform Annual Cost (EUAC) of IDR 1,390,833,816.62 and an EUAC per square yard of pavement of IDR 56,648.49. This alternative yields the lowest life cycle cost and annual cost over a 20-year design life.

***Keywords**: Pavement Condition Index (PCI), Life Cycle Cost Analysis (LCCA), Equivalent Uniform Annual Cost (EUAC), Capital Recovery Factor (CRF), Present Value (PV), EUAC Per Square Yard of Pavement.*

How to Cite: Saiful; Taslim Bahar; Ratnasari Ramlan (2026) Optimal Maintenance Strategy for the Palu–Kulawi Road Section Based on Life Cycle Cost Analysis (LCCA) (Case Study: Guru Tua Road). *International Journal of Innovative Science and Research Technology,* 11(3), 2342-2352. https://doi.org/10.38124/ijisrt/26mar1214

I. INTRODUCTION

Road infrastructure is not merely a physical network that connects locations, but also constitutes a crucial pillar in the development of a society. The quality of road infrastructure has profound impacts on various aspects of life, ranging from economic activities to environmental conditions. Along with population growth and increasing urbanization, the demand for an efficient transportation system continues to rise. Therefore, the maintenance and condition mapping of road infrastructure have become increasingly important.

The serviceability of a road gradually decreases as its service life increases, until eventually the road reaches a condition where traffic flow begins to be disrupted. In many cases, road sections that have been constructed experience deterioration much faster than their intended design life.

In Indonesia, one of the methods used to evaluate road conditions is the Pavement Condition Index (PCI), commonly referred to as the Indeks Kondisi Perkerasan (IKP). This method is based on visual surveys, in which pavement surface distresses are identified, measured, and classified according to their severity levels. The assessment results are then converted into an IKP value on a scale ranging from 0 to 100, which is

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

subsequently used to classify pavement conditions into several categories, such as good, fair, minor damage, or severe damage.

In the regional context, road maintenance activities are often constrained by limited annual budget allocations. Consequently, the selection of maintenance strategies cannot rely solely on technical condition assessments. An economic analysis is required to ensure that maintenance decisions are not only technically appropriate but also cost-efficient in the long term. One of the methods widely applied internationally for this purpose is Life Cycle Cost Analysis (LCCA). According to the Federal Highway Administration (FHWA, 1998), LCCA is a systematic approach used to evaluate maintenance alternatives by calculating the total life cycle costs of an asset over its design life in present value terms (Net Present Cost). The life cycle concept is used to determine the appropriate timing of pavement maintenance to support the intended design life, while life cycle cost analysis is required to estimate the total costs incurred throughout the planned service life of the road (Dina Rahmawati, 2014). LCCA considers all direct and indirect costs throughout the infrastructure's service life, including initial construction costs, routine maintenance, rehabilitation, and the economic impacts on road users (Reherman, 2006). The LCCA method has been widely applied to assess long-term cost efficiency in road infrastructure projects. A consistent and valid method for evaluating the life cycle cost of infrastructure assets is the Life Cycle Cost Analysis (LCCA) approach (Susanti Betty and Wirahadikusumah Reini D, 2014). By applying this method, it is possible to determine the most economical maintenance strategy among several available road maintenance alternatives.

II. LITERATURE REVIEW

A. Pavement Condition Index (PCI)

The Pavement Condition Index (PCI), known in Indonesia as Indeks Kondisi Perkerasan (IKP), is an indicator used to assess the condition of road pavement. The PCI is developed to support the Road Maintenance Management System through the continuous updating of data required for the preparation of maintenance programs. The Pavement Condition Index is a visual survey method used to evaluate pavement conditions in Indonesia. PCI is expressed in the form of a numerical index on a scale ranging from 0 to 100, where higher values indicate good pavement conditions and lower values indicate severe deterioration.

This method was developed by the Center for Research and Development of Roads and Bridges (Pusat Penelitian dan Pengembangan Jalan dan Jembatan) as an instrument to support road management. It adopts the basic principles of international methods such as the Pavement Condition Index (PCI), while being adapted to traffic characteristics and climatic conditions in Indonesia (Bina Marga, 2017).

The Pavement Condition Index is measured on a scale ranging from 0 to 100. On this scale, a value of 0 represents the worst possible pavement condition, while a value of 100 represents the best possible pavement condition. By using the PCI, relevant stakeholders can conduct objective assessments of pavement conditions and plan appropriate maintenance programs to repair or preserve pavement performance in order to maintain optimal service levels.

A higher PCI value indicates better pavement conditions, whereas a lower PCI value reflects poorer pavement conditions. Therefore, the PCI provides an objective and rational basis for determining the necessary maintenance and rehabilitation programs as well as establishing priorities for road maintenance interventions (Fahrulyanda Ar Rafidin, Burhamtoro, and Helik Susilo, 2023).

The Pavement Condition Index (PCI) method, has several key advantages, including its simplicity, low cost, and ease of implementation. The PCI survey only requires visual observation of pavement surface distresses, making it highly suitable for use by local government agencies that often face limitations in resources and equipment (Puslitbang Jalan dan Jembatan, 2016). The PCI results are expressed in the form of an index value, which is easy to interpret and can be directly used to classify pavement conditions and determine appropriate maintenance requirements (Bina Marga, 2017).

However, the PCI method also has certain limitations. Since it only evaluates surface-level damage, it cannot fully represent the structural condition of the underlying pavement layers. In fact, structural deterioration is often the primary cause of declining pavement performance. In addition, PCI results may be influenced by the subjectivity of the surveyors, which means that trained and experienced personnel are required to ensure consistency and reliability in the assessment process (Setiadji, 2015). The PCI method also does not incorporate ride quality factors, such as driving comfort, which are typically measured using the International Roughness Index (IRI).

Nevertheless, considering its cost efficiency and practical implementation, the PCI method remains one of the most widely used approaches in road maintenance management in Indonesia, particularly at the district and municipal levels.

B. Life Cycle Cost Analysis (LCCA)

According to the American Association of State Highway and Transportation Officials (AASHTO, 1998), Life Cycle Cost Analysis (LCCA) is a process used to evaluate the total economic value of a feasible project alternative by analyzing both initial costs and discounted future costs throughout the project's service life. These costs include maintenance, user costs, reconstruction, rehabilitation, restoration, and resurfacing. AASHTO emphasizes the importance of considering time-related factors, such as the time value of money and the discount rate.

In Indonesia, the Ministry of Public Works and Housing (PUPR) has also adopted the principles of LCCA in infrastructure project planning and evaluation. In this context, LCCA is applied in determining national road maintenance strategies to select alternatives that provide the greatest benefits with the most efficient cost allocation. Life Cycle

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

Cost Analysis (LCCA) is a powerful decision-making tool in road infrastructure management. This methodology has become increasingly relevant in Indonesia due to growing demands for efficiency in road development and maintenance budgets. Through a systematic and data-driven approach, LCCA assists governments and stakeholders in selecting infrastructure management strategies that are economically efficient in the long term.

Life Cycle Cost Analysis (LCCA) is a systematic method used to evaluate the total cost of an infrastructure asset throughout its life cycle, including planning, construction, maintenance, operation, and the residual value at the end of its service life. LCCA does not only assess the initial cost but focuses primarily on the long-term economic efficiency of various infrastructure management alternatives.

According to the Federal Highway Administration (FHWA, 1998) and the Directorate General of Highways (Bina Marga, 2017), the implementation of LCCA generally involves several main stages as follows:

➢ *Determination of Objectives and Scope of Analysis*

The initial step is to clearly define the objective of the LCCA. For example, the analysis may aim to compare two or more pavement alternatives (such as rigid versus flexible pavement) or to determine the most efficient maintenance strategy based on life cycle costs. The scope of the analysis should include:

- The analysis period (typically 20–30 years for road infrastructure)
- Location and environmental conditions
- Traffic characteristics and traffic growth projections
- Availability of cost data

➢ *Identification of Treatment Alternatives*

At this stage, several feasible technical alternatives are developed to allow a fair comparison. For example, Alternative 1 may involve flexible pavement with an overlay every 10 years, while Alternative 2 may involve rigid pavement with minor periodic repairs.

- Each alternative must:
- Be technically feasible
- Be applicable to the project location
- Use consistent baseline assumptions

➢ *Identification and Estimation of Cost Components*

The costs considered in LCCA include:

- Initial cost: construction, mobilization, and design costs
- Maintenance and rehabilitation (M&R) costs: routine and periodic maintenance
- Operational and user costs: user delay costs and vehicle operating costs
- Salvage value: the remaining value of the asset at the end of the analysis period

Cost estimation is generally based on unit price standards (e.g., AHSP Bina Marga), historical data, and predictions of maintenance and rehabilitation events based on the technical service life of the pavement.

➢ *Determination of the Time Value of Money (Discounting)*

Money has a time value; therefore, all future costs must be discounted to their present value (Present Worth) using a discount rate. The general formula is:

$$PW = \frac{F}{(1+r)^n}$$

Where:

PW = Present Worth

F = Future value

r = Discount rate

n = Year to-n

The selected discount rate usually refers to socio-economic values or institutional standards, commonly ranging between 6–8%.

➢ *Calculation of Total Life Cycle Cost*

After all costs have been estimated and discounted, the total life cycle cost for each alternative is calculated. These costs are then compared to determine the most economical option. Several analytical methods may be used, including:

- Net Present Value (NPV)
- Benefit–Cost Ratio (BCR) (if benefits are included)
- Equivalent Uniform Annual Cost (EUAC) for equivalent annual costs

➢ *Sensitivity Analysis*

This stage evaluates how sensitive the analysis results are to changes in key assumptions, such as: Discount rate, Material prices, Maintenance frequency and Traffic growth Sensitivity analysis helps support more reliable decision-making, particularly when some parameters are based on estimates.

➢ *Decision Making*

The alternative with the lowest life cycle cost and the best performance is generally selected. However, decision-making may also consider several non-economic aspects, including:

- Environmental impacts
- Ease of implementation
- Road service performance.

III. RESEARCH METHOD

A. Type of Research

This study was conducted through several systematically arranged stages to determine the optimal road maintenance

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

strategy for the Guru Tua Road section. The research stages began with problem formulation and continued through a series of analytical processes, culminating in the determination of an appropriate road maintenance strategy based on the integration of pavement condition analysis and life cycle cost analysis.

B. Research Location

The research location is Guru Tua Road Section, which is an arterial road connecting Palu City with Kulawi District in Sigi Regency, Central Sulawesi Province. Administratively, this road section begins at the boundary of Palu City, specifically in South Palu District, and extends to Dolo District in Sigi Regency.

Based on the List of Road Network Sections According to Their Functions in Central Sulawesi Province, Guru Tua Road is classified as one of the provincial roads in Central Sulawesi and is categorized as a Secondary Arterial Road. The starting point of the road section is located at the three-way intersection of Towua Street and Karajalemba 1 Street in Kalukubula Village, while the endpoint is located at the Welcome Gate to the Culinary and Fishing Tourism Area in Dolo District. The total length of this road section is 3.96 km.

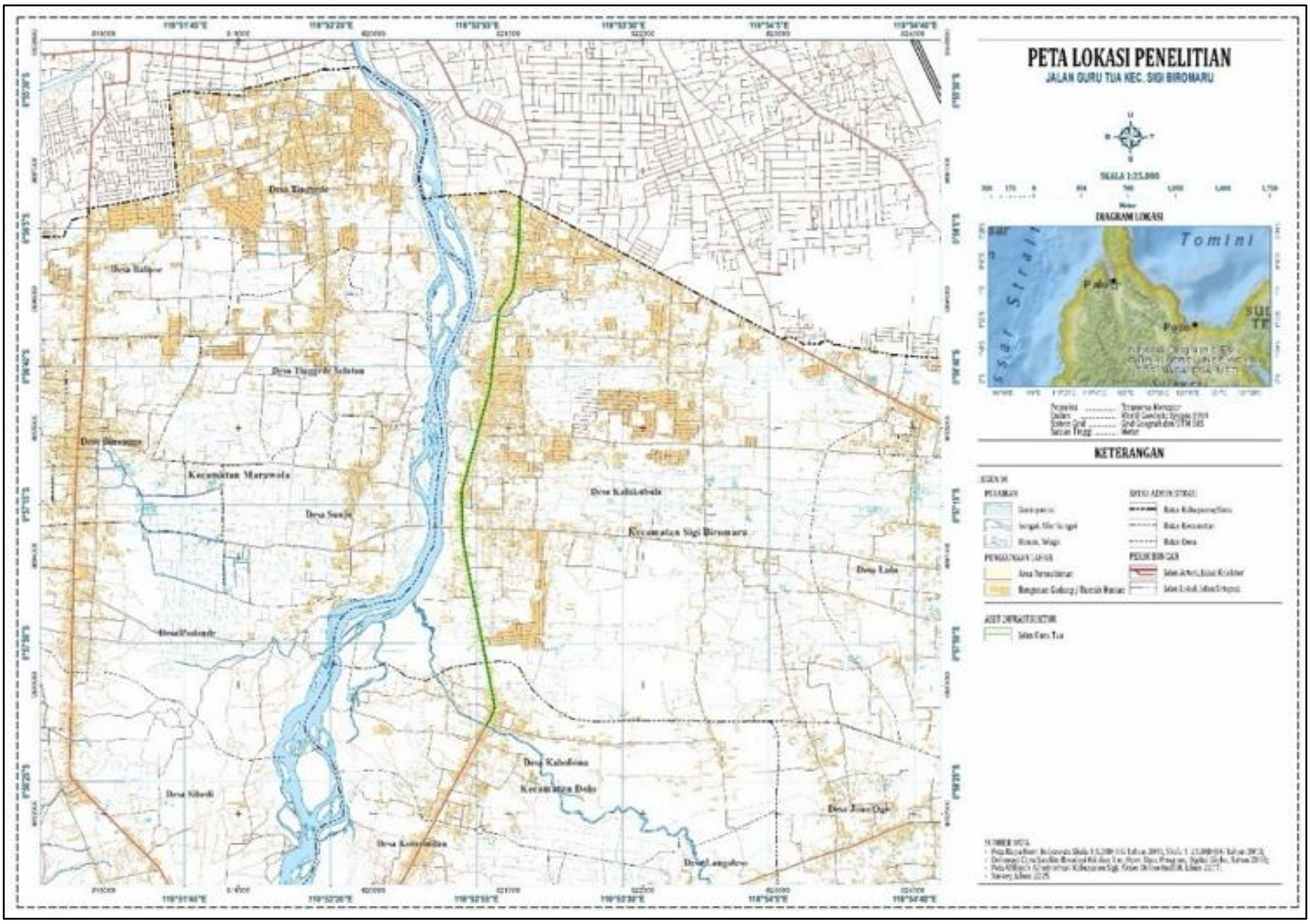

Fig 1 Research Location

C. Data Collection Techniques

This study utilizes a combination of primary data and secondary data as the basis for conducting pavement condition analysis and life cycle cost calculations for each alternative road maintenance strategy. The data collection and utilization processes were carried out systematically to ensure the accuracy and relevance of the research results.

The data collection stage represents a crucial step in this study because the data obtained serve as the foundation for analyzing pavement conditions using the Pavement Condition Index (PCI) method, known in Indonesia as Indeks Kondisi Perkerasan (IKP), as well as for analyzing road maintenance costs using the Life Cycle Cost Analysis (LCCA) method. Data were collected systematically by utilizing two types of sources: primary data and secondary data.

➢ *Primary Data Collection*

Primary data were obtained through direct field surveys conducted on the Guru Tua Road section, which served as the research location. The purpose of this survey was to obtain information regarding the actual condition of the road pavement.

Primary data collection was carried out by observing and recording various types of pavement damage occurring in each predetermined sample unit. The data collected include the type

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

of pavement distress, the extent of damage (area or length), and the severity level of the damage.

In addition, measurements of road dimensions such as road width and segment length were conducted to support the calculation of damage density in the PCI method. The pavement condition data obtained from the field survey were subsequently used as the basis for calculating the PCI value for each sample unit.

➤ *Secondary Data Collection*

Secondary data were obtained from various sources relevant to this research. These data include planning documents, technical guidelines, and standards used in the analysis of road maintenance.

The secondary data were obtained from several institutions and relevant literature sources, including:

- Maintenance planning documents from the Department of Highways and Spatial Planning (Dinas Bina Marga dan Tata Ruang) of Central Sulawesi Province.
- Technical data and unit price standards from the Unit Price Analysis (AHSP) provided by the Highways Division of the Public Works and Housing Agency (PUPR) of Central Sulawesi.
- Average Daily Traffic (ADT) data obtained from the Highways Division of PUPR Central Sulawesi.
- Technical guidelines for the PCI survey issued by the Research and Development Center of PUPR, contained in the PCI Guideline (Pd 01-2016-B, 2016), as well as documentation from the Federal Highway Administration (FHWA, 1998) related to the Life Cycle Cost Analysis (LCCA) approach.

Through the collection of both primary and secondary data, comprehensive information was obtained regarding the technical condition of the pavement as well as the economic parameters required for road maintenance cost analysis. The collected data were then processed and analyzed in subsequent stages using the PCI method to determine pavement conditions and the LCCA method to evaluate alternative road maintenance strategies from an economic perspective.

D. Data Analysis Technique

➤ *Pavement Condition Index (PCI) Data Analysis*

Based on the Guidelines for Determining the Pavement Condition Index published by the Research and Development Center for Roads and Bridges of the Ministry of Public Works and Housing (Puslitbang Jalan dan Jembatan PUPR, 2016), the PCI method begins with the survey preparation stage, which involves determining the road segments and sample units.

Subsequently, a visual field survey is conducted to identify 19 types of pavement surface distress, including their dimensions such as area, length, or depth, as well as their severity levels (low, medium, and high). The collected distress data are then processed to obtain damage density values. These density values are subsequently converted into Deduct Values based on the standard curves provided in the PCI guidelines.

The PCI value for each sample unit is calculated by subtracting the total deduct value from the base value of 100. These values are then averaged to obtain the PCI value for each road segment and the overall PCI value for the road section. The final stage of the method is the classification of pavement conditions based on the PCI value, which serves as the basis for determining the appropriate road maintenance actions.

➤ *Life Cycle Cost Analysis (LCCA) Data Analysis*

The Life Cycle Cost Analysis (LCCA) method in this study is used to compare several alternative road maintenance strategies based on the total cost over the infrastructure's design life. This method enables more rational decision-making by considering the long-term cost efficiency of each maintenance alternative. The stages of the LCCA analysis in this study are described as follows:

- *Identification of Road Maintenance Alternatives*

Several maintenance strategy alternatives were formulated based on the PCI (IKP) values, dominant types of pavement distress, and common road maintenance practices. The alternatives evaluated in this study for the Guru Tua Road section are presented in the following table.

The Do Minimum strategy is used as the baseline scenario in the life cycle cost analysis. This scenario includes only minimal routine maintenance to keep the road operational, without major interventions such as overlays, rehabilitation, or reconstruction. The results of the Do Minimum analysis serve as a benchmark for comparison with other alternatives, allowing for the evaluation of cost-effectiveness among different maintenance strategies.

- *Determination of the Analysis Period*

The analysis period is set at 20 years, in accordance with the standard design life of flexible pavements. This period encompasses the entire maintenance life cycle and allows for a comprehensive comparison of total costs.

- *Estimation of Maintenance Schedule and Costs*

For each alternative, the maintenance schedule and frequency are projected based on pavement deterioration curves. Cost estimation is conducted using the Unit Price Analysis (AHSP) standards issued by the Directorate General of Highways (Bina Marga) or applicable local unit prices.

- *Discounting Future Costs to Present Value*

All future costs are discounted to the base year using a discount rate of 8% per year. This step accounts for the time value of money, ensuring that costs occurring at different times can be compared on an equivalent basis.

- *Calculation of Net Present Cost (NPC)*

Road maintenance involves both agency costs and user costs, which are calculated annually for each maintenance alternative. To obtain the Net Present Cost (NPC) of each

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

alternative, all discounted costs are summed over the entire service life of the road, based on the discount rate established in the previous stage.

- *Equivalent Uniform Annual Cost (EUAC)*

The Equivalent Uniform Annual Cost (EUAC) is an engineering economic analysis method used to convert total life cycle costs into an equivalent uniform annual cost. This concept is based on the time value of money, which recognizes that the value of money changes over time due to interest rates or discount rates.

In the context of LCCA, EUAC is used to compare multiple alternatives that have different cost patterns throughout the analysis period by expressing them in equivalent annual terms.

- *Comparison and Evaluation of Alternatives*

The NPC values of each alternative are compared to determine the strategy with the lowest total cost over the analysis period. The alternative with the smallest NPC is considered the most economically efficient option.

- *Interpretation of Results and Determination of Optimal Strategy*

The results of the LCCA analysis are interpreted in conjunction with the technical data obtained from the PCI (IKP) analysis to determine the optimal maintenance strategy. The selected strategy is not only economically efficient but also consistent with the actual pavement condition and level of deterioration.

IV. RESULTS

The Guru Tua Road section is one of the important road segments within the road network of Sigi Regency, Central Sulawesi Province. This road connects Palu City with the Kulawi area, thereby serving as a primary corridor for the distribution of goods and services as well as community mobility. Within the road network hierarchy, Guru Tua Road is classified as a Secondary Arterial Road, accommodating regional traffic from the urban center toward rural and hinterland areas.

In general, the road has a length of approximately 3.96 kilometers with an average pavement width of 5 meters. The pavement type is flexible pavement (asphalt/hotmix), which currently exhibits various forms of surface deterioration, including cracking, potholes, and deformation. The variation in damage conditions makes the Guru Tua Road section highly relevant for analysis using the Pavement Condition Index (PCI) method, known in Indonesia as Indeks Kondisi Perkerasan (IKP).

From a traffic perspective, Guru Tua Road experiences a relatively high level of vehicle activity, particularly from light vehicles and freight transport, as it serves as a main access route for the distribution of agricultural products, plantation commodities, and logistics from Kulawi to Palu City. During peak hours, traffic tends to become congested, imposing additional stress on the pavement structure. This condition indicates that road maintenance for this segment must be carefully planned to ensure the sustainability of its service performance.

Given its strategic role, the Guru Tua Road section functions not only as a transportation link but also as a key support for economic activities, tourism, disaster response, and social interactions within the Palu–Kulawi region. Therefore, an evaluation of road maintenance strategies based on the PCI (IKP) and Life Cycle Cost Analysis (LCCA) methods is essential to provide optimal recommendations for maintaining the performance of this road segment.

A. Results of Road Condition Survey Using the PCI Method

A field survey was conducted to determine the actual pavement condition of the Guru Tua Road section. The survey employed the Pavement Condition Index (PCI) method, known in Indonesia as Indeks Kondisi Perkerasan (IKP), as established by the Research and Development Center for Roads and Bridges (Puslitbang Jalan dan Jembatan, 2016) as one of the official guidelines for road condition assessment in Indonesia. This method was selected because it provides a quantitative representation of pavement deterioration, which can serve as a basis for determining appropriate types and strategies of road maintenance.

The survey was carried out by dividing the road section into sample units. Based on the preliminary survey, information regarding the length and average width of the Guru Tua Road section was obtained. To ensure that each sample unit complies with the PCI guidelines, the road was divided into segments at 50-meter intervals.

The next stage involved recording the type of pavement distress, the severity level (low, medium, or high), and measuring the dimensions of the damage (length, width, or depth). The field data were then processed to calculate the damage density and the corresponding deduct values, which were subsequently used to determine the PCI values for each sample unit, road segment, and the overall road section.

Segments with relatively high PCI values (≥ 85) can be classified as being in good condition, where the observed damage is limited to minor distresses such as hairline cracks (hair cracks) and small patches. Segments with PCI values ranging from 70 to 84 are categorized as being in fair condition, typically characterized by longitudinal and transverse cracking as well as surface wear.

Segments with PCI values between 55 and 69 indicate poor (minor damage) conditions, marked by the presence of alligator cracking, surface deformation such as rutting, and the initial formation of small potholes. Under these conditions, pavement rehabilitation is required to maintain the structural capacity of the road.

Meanwhile, segments with PCI values below 55 are classified as being in severe condition, with extensive damage including large potholes, severe cracking, and surface depressions. These segments can no longer be effectively treated through routine or periodic maintenance and instead

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

require reconstruction to restore the road to an acceptable level of service.

In the implementation stage of the Pavement Condition Index (PCI) method, known in Indonesia as Indeks Kondisi Perkerasan (IKP), the initial step involves determining the sample units that serve as the basis for the road condition survey. According to the PCI Guidelines issued by the Research and Development Center for Roads and Bridges (Puslitbang Jalan dan Jembatan, 2016), a sample unit represents a segment of a road section with a standard area of 225 m², with a tolerance of ±90 m², depending on variations in road width and length in the field. The determination of sample units is intended to ensure that each observed segment has a relatively uniform proportion in terms of length and width, allowing the survey results to be analyzed consistently.

Based on the total road length of 3.96 km, this study divides the road into sample units at 50-meter intervals, resulting in a total of 79 sample units along the Guru Tua Road section. This interval provides a sufficiently high density of observation points, enabling a more detailed evaluation of pavement conditions throughout the road section.

➢ *The Selection of the 50-Meter Interval is Based on Two Main Considerations:*

- Consistency with guideline requirements, ensuring that the area of each sample unit remains within the acceptable range of 135–315 m² (225 ± 90 m²).
- Analytical accuracy, where a denser observation interval (50 meters) allows for more detailed detection of variations in pavement surface distress along the road section under study.

Based on the frequency of pavement distress, the dominant types of damage on the Guru Tua Road section are longitudinal/transverse cracking (57 occurrences), edge cracking (51), patching (40), reflection cracking (29), and alligator cracking (25). These damages occur repeatedly across most sample units and significantly contribute to pavement deterioration.

The high occurrence of cracking indicates material fatigue, temperature effects, and repeated traffic loads, reflecting a decline in both functional and structural performance. Edge cracking suggests issues with shoulder support and drainage, while frequent patching indicates previous temporary repairs that have not fully resolved underlying problems. Reflection cracking shows the influence of existing pavement layers, particularly in overlaid sections, whereas alligator cracking signals serious structural failure.

The variation in severity—from minor to severe—indicates that different maintenance actions are required, ranging from routine maintenance to rehabilitation and reconstruction. Overall, these findings provide a basis for determining PCI values and formulating appropriate road maintenance strategies.

After calculating the Pavement Condition Index (PCI/IKP) values for all sample units along the Guru Tua Road section (as presented in Appendix 2), the next step is to perform a recapitulation of PCI values to obtain a more comprehensive overview of the pavement condition. This recapitulation is carried out by grouping PCI values based on road segmentation, allowing for the identification of variations in pavement conditions across different parts of the study section.

In this study, the Guru Tua Road section, with a total length of approximately 3.9 km, is divided into three main segments: 0+000 – 1+300, 1+300 – 2+600, and 2+600 – 3+900. This segmentation aims to facilitate a more systematic analysis of road conditions and to identify sections with relatively higher levels of deterioration compared to others. The PCI value for each segment is obtained by calculating the average PCI value of all sample units within the respective segment.

Table 1 Recapitulation of PCI Values Per Road Segment

Segment	STA (Km)	Average PCI
Segment 1	0+000 – 1+300	78.88
Segment 2	1+300 – 2+600	75.43
Segment 3	2+600 – 3+900	68.45

The classification of road conditions based on the Pavement Condition Index (PCI/IKP) is essential as it provides an objective basis for decision-makers in selecting appropriate maintenance strategies. Furthermore, this classification serves as a key input in the Life Cycle Cost Analysis (LCCA) used in this study to compare the cost efficiency of various maintenance alternatives over a 20-year analysis period. By integrating PCI results with road maintenance principles in accordance with relevant regulations, maintenance strategies for the Guru Tua Road section can be formulated in a more systematic, effective, and sustainable manner. Based on the data processing results (see Appendix II), the road conditions can be classified as follows:

Table 2 Road Condition Classification

Segment (Km)	Average PCI	Road Condition	Type of Maintenance
0+000 – 1+300	78.88	Fair	Periodic Maintenance
1+300 – 2+600	75.43	Fair	Periodic Maintenance
2+600 – 3+900	68.45	Poor (Minor)	Rehabilitation

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

Based on Table 2, Segment 1 (Km 0+000–1+300) with an average PCI value of 78.88 and Segment 2 (Km 1+300–2+600) with a value of 75.43 are both classified as being in fair condition. Therefore, the appropriate treatment for these segments is periodic maintenance, aimed at preserving and improving both the structural and functional performance of the pavement.

Meanwhile, Segment 3 (Km 2+600–3+900) has an average PCI value of 68.45, which falls under the poor (minor damage) category. Consequently, rehabilitation measures are required to restore the pavement's serviceability.

The determination of these alternative strategies is crucial, as each option carries different technical and economic implications. Strategies with minimal intervention may appear less costly in the short term; however, they often result in higher long-term costs due to faster pavement deterioration. In contrast, strategies involving periodic maintenance or rehabilitation can reduce overall life cycle costs within the analysis horizon.

By establishing these alternatives, the LCCA can be conducted objectively to evaluate the total life cycle cost of each strategy. This enables the identification of the most economically efficient maintenance strategy to be implemented on the Guru Tua Road section.

In this study, sensitivity analysis was conducted using three variations of discount rates, namely 6%, 8%, and 10%. The 8% discount rate was established as the base case, as it is commonly applied in the economic feasibility evaluation of infrastructure projects in Indonesia. This value represents the social discount rate that is typically used in public investment analysis, particularly in the road infrastructure sector.

Meanwhile, the 6% and 10% discount rates were employed as sensitivity test scenarios to examine the extent to which changes in the time value of money affect the results of the economic evaluation. The selection of this range is based on the spectrum of social interest rates and discount parameters commonly applied in national infrastructure investment planning practices, as referenced by the Ministry of National Development Planning (Bappenas) and the Ministry of Public Works in project evaluation guidelines.

Table 3 Net Present Cost (NPC) Results at 6% Discount Rate – Alternative 1, Segment 1

Year	Type of Maintenance	Cost (Ct) (IDR)	Discount Factor	Present Value
1	Periodic Maintenance	171,373,000	0.943	161,672,641.509
2	Routine Maintenance	120,617,000	0.890	107,348,700.605
3	Routine Maintenance	120,617,000	0.840	101,272,359.062
4	Routine Maintenance	120,617,000	0.792	95,539,961.379
5	Periodic Maintenance	171,373,000	0.747	128,059,874.859
6	Routine Maintenance	120,617,000	0.705	85,030,225.506
7	Routine Maintenance	120,617,000	0.665	80,217,193.874
8	Routine Maintenance	120,617,000	0.627	75,676,597.994
9	Periodic Maintenance	171,373,000	0.592	101,435,415.391
10	Routine Maintenance	120,617,000	0.558	67,351,902.807
11	Routine Maintenance	120,617,000	0.527	63,539,530.950
12	Rehabilitation	3,912,013,000	0.497	1,944,150,610.915
13	Routine Maintenance	120,617,000	0.469	56,549,956.346
14	Routine Maintenance	120,617,000	0.442	53,349,015.421
15	Periodic Maintenance	171,373,000	0.417	71,507,965.253
16	Routine Maintenance	120,617,000	0.394	47,480,433.803
17	Routine Maintenance	120,617,000	0.371	44,792,862.078
18	Routine Maintenance	120,617,000	0.350	42,257,417.055
19	Routine Maintenance	120,617,000	0.331	39,865,487.787
20	Routine Maintenance	120,617,000	0.312	37,608,950.743
Total		**6,406,760,000**		**3,404,707,103.336**

Table 4 Net Present Cost (NPC) Results at 6% Discount Rate – Alternative 2, Segment 1

Year	Type of Maintenance	Cost (Ct) (IDR)	Discount Factor	Present Value
1	Rehabilitation	3,912,013,000	0.943	3,690,578,301.887
2	Routine Maintenance	120,617,000	0.890	107,348,700.605
3	Routine Maintenance	120,617,000	0.840	101,272,359.062
4	Periodic Maintenance	171,373,000	0.792	135,743,467.350
5	Routine Maintenance	120,617,000	0.747	90,132,039.037
6	Routine Maintenance	171,373,000	0.705	120,811,202.697
7	Routine Maintenance	120,617,000	0.665	80,217,193.874
8	Routine Maintenance	120,617,000	0.627	75,676,597.994
9	Routine Maintenance	120,617,000	0.592	71,393,016.976

Year	Type of Maintenance	Cost (Ct) (IDR)	Discount Factor	Present Value
10	Routine Maintenance	171,373,000	0.558	95,693,788.104
11	Routine Maintenance	120,617,000	0.527	63,539,530.950
12	Periodic Maintenance	171,373,000	0.497	85,167,130.744
13	Routine Maintenance	120,617,000	0.469	56,549,956.346
14	Routine Maintenance	120,617,000	0.442	53,349,015.421
15	Reconstruction	5,206,554,000	0.417	2,172,513,071.033
16	Routine Maintenance	120,617,000	0.394	47,480,433.803
17	Routine Maintenance	120,617,000	0.371	44,792,862.078
18	Routine Maintenance	120,617,000	0.350	42,257,417.055
19	Routine Maintenance	120,617,000	0.331	39,865,487.787
20	Routine Maintenance	120,617,000	0.312	37,608,950.743
Total		**11.492.697.000**		**7.211.990.523,544**

Table 5 Net Present Cost (NPC) Results at 6% Discount Rate – Alternative 3, Segment 1

Year	Type of Maintenance	Cost (Ct) (IDR)	Discount Factor	Present Value
1	Reconstruction	5,206,554,000	0.943	4,911,843,396.226
2	Routine Maintenance	120,617,000	0.890	107,348,700.605
3	Routine Maintenance	120,617,000	0.840	101,272,359.062
4	Routine Maintenance	120,617,000	0.792	95,539,961.379
5	Routine Maintenance	120,617,000	0.747	90,132,039.037
6	Periodic Maintenance	171,373,000	0.705	120,811,202.697
7	Routine Maintenance	120,617,000	0.665	80,217,193.874
8	Routine Maintenance	120,617,000	0.627	75,676,597.994
9	Routine Maintenance	120,617,000	0.592	71,393,016.976
10	Periodic Maintenance	171,373,000	0.558	95,693,788.104
11	Routine Maintenance	120,617,000	0.527	63,539,530.950
12	Routine Maintenance	120,617,000	0.497	59,942,953.727
13	Routine Maintenance	120,617,000	0.469	56,549,956.346
14	Routine Maintenance	120,617,000	0.442	53,349,015.421
15	Periodic Maintenance	171,373,000	0.417	71,507,965.253
16	Routine Maintenance	120,617,000	0.394	47,480,433.803
17	Routine Maintenance	120,617,000	0.371	44,792,862.078
18	Routine Maintenance	120,617,000	0.350	42,257,417.055
19	Routine Maintenance	120,617,000	0.331	39,865,487.787
20	Routine Maintenance	120,617,000	0.312	37,608,950.743
Total		**7.650.545.000**		**6.266.822.829,115**

Table 6 Summary of Alternatives with Discount Rates of 6%, 8%, and 10% – Segment 1

No	Alt	NPC 6%	NPC 8%	NPC 10%
1	**Alt. 1**	3.404.707.103	2.812.782.023	2.346.269.505
2	**Alt. 2**	7.211.990.523	6.411.044.608	5.790.195.563
3	**Alt. 3**	6.266.822.829	5.964.931.558	5.710.829.262

Table 7 Summary of Alternatives with Discount Rates of 6%, 8%, and 10% – Segment 2

No	Alt	NPC 6%	NPC 8%	NPC 10%
1	**Alt. 1**	2.967.576.620	2.383.122.454	1.923.652.797
2	**Alt. 2**	8.037.561.431	7.276.719.331	6.688.330.280
3	**Alt. 3**	6.069.703.705	5.931.002.843	5.802.595.410

Table 8 Summary of Alternatives with Discount Rates of 6%, 8%, and 10% – Segment 3

No	Alt	NPC 6%	NPC 8%	NPC 10%
1	**Alt. 1**	9.306.737.203	8.459.506.952	7.773.075.975
2	**Alt. 2**	9.065.116.898	8.174.362.500	7.477.990.756
3	**Alt. 3**	6.776.317.081	6.540.515.482	6.333.402.967

The calculation results indicate that for all alternatives, the Net Present Cost (NPC) decreases as the discount rate increases. This condition is consistent with the time value of money theory, where a higher discount rate results in a lower present value of future costs. At a 6% discount rate, the NPC values are relatively higher because future costs still carry

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

significant weight in present value terms. Conversely, at a 10% discount rate, the contribution of future costs to the present value becomes smaller, leading to a reduction in the total NPC.

Based on the results of the sensitivity analysis using three discount rates (6%, 8%, and 10%), it can be concluded that changes in the discount rate affect the magnitude of the Net Present Cost (NPC), but do not alter the ranking of alternative priorities. Therefore, the selection of the preferred alternative remains consistent across the tested discount rate scenarios.

In national investment planning practices, the range of discount rates used in the economic evaluation of infrastructure projects generally falls between 6% and 10%. A discount rate of 8% is often adopted as a moderate scenario, as it is considered representative of Indonesia's medium-term macroeconomic conditions.

B. Equivalent Uniform Annual Cost (EUAC) Analysis

Equivalent Uniform Annual Cost (EUAC) is an economic evaluation method used to convert the total life-cycle cost of a project into an equivalent uniform annual cost over its design life. This method is derived from the Life Cycle Cost Analysis (LCCA) approach and is commonly applied in infrastructure asset management to compare multiple alternatives with either similar or different service lives.

Conceptually, while the Net Present Cost (NPC) represents the total cost in present value terms, EUAC expresses the average annual cost that is economically equivalent over the analysis period.

Table 9 Total Cost of Each Alternative

Alt	Segment 1	Segment 2	Segment 3	TOTAL
Alt. 1	2.812.782.024	2.383.122.455	8.459.506.953	13.655.411.431
Alt. 2	6.411.044.608	7.276.719.332	8.174.362.500	21.862.126.440
Alt. 3	5.964.931.558	5.931.002.844	6.540.515.483	18.436.449.884

Table 10 Cost Indicators for Each Alternative

Alt	CRF	PV	EUAC	EUAC per square yard of pavement
Alt. 1	0,102	13.655.411.431	1.390.833.816	56.648,49
Alt. 2	0,102	21.862.126.440	2.226.705.867	90.693,46
Alt. 3	0,102	18.436.449.884	1.877.793.143	76.482,29

The economic analysis in this study was conducted using the Life Cycle Cost Analysis (LCCA) method to evaluate the cost feasibility of each road treatment alternative over a 20-year design life. The calculations consider the time value of money by applying an interest rate that yields a Capital Recovery Factor (CRF) of 0.102.

The results indicate that Alternative 1 has a Present Value (PV) of IDR 13,655,411,431, with an Equivalent Uniform Annual Cost (EUAC) of IDR 1,390,833,816.62 and an EUAC per square yard of pavement of IDR 56,648.49. These values are the lowest among all alternatives.

Alternative 2 yields a PV of IDR 21,862,126,440, with an EUAC of IDR 2,226,705,867.52 and an EUAC per square yard of IDR 90,693.46. These values are the highest among the three alternatives, indicating the greatest annual cost burden over the design life.

Meanwhile, Alternative 3 has a PV of IDR 18,436,449,884, with an EUAC of IDR 1,877,793,143.59 and an EUAC per square yard of IDR 76,482.29, placing it between Alternative 1 and Alternative 2.

These results demonstrate that a higher PV corresponds to a higher equivalent annual cost burden over the design life. Alternative 1 consistently produces the lowest EUAC values, both in terms of total annual cost and cost per unit area of pavement. This indicates that the strategy implemented in Alternative 1 provides greater cost efficiency compared to the other alternatives, as it minimizes the annual budget burden while reducing the cost per unit of road service.

V. CONCLUSION

➢ *Based on the Findings and Discussions Presented in this Study, the Following Conclusions can be Drawn:*

- Based on the evaluation results of the Pavement Condition Index (PCI), it is observed that Segment 1 (Km 0+000–1+300) has an average PCI value of 78.88 and Segment 2 (Km 1+300–2+600) has an average value of 75.43. Both segments fall into the fair condition category; therefore, the appropriate treatment is periodic maintenance. Meanwhile, Segment 3 (Km 2+600–3+900) has an average PCI value of 68.45, which is classified as lightly damaged condition, thus requiring rehabilitation measures to restore the pavement's serviceability.
- In Segment 1 and Segment 2, Alternative 1 begins with periodic maintenance in the first year, based on the PCI survey results indicating values of 78.88 and 75.43 (fair condition), thereby necessitating periodic maintenance to preserve the functional quality of the pavement. This strategy is followed by predominantly routine maintenance and periodic maintenance in years 5, 9, and 15, with rehabilitation carried out in year 12. Alternative 2 starts with rehabilitation in the first year to restore structural capacity from the outset, followed by consistent routine maintenance and periodic maintenance in years 4 and 12, with reconstruction implemented in year 15. Meanwhile, Alternative 3 applies reconstruction in the first

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar1214

year as a comprehensive structural treatment, followed by routine maintenance and periodic maintenance in years 6, 10, and 15.

- In Segment 3, Alternative 1 begins with rehabilitation in the first year, based on the PCI survey result of 68.45 (lightly damaged condition), requiring rehabilitation to restore both structural and functional capacity. Following the initial rehabilitation, the maintenance strategy continues with predominantly routine maintenance to maintain the level of service, along with periodic maintenance in years 4, 8, and 15 to slow the rate of deterioration. Subsequently, reconstruction is carried out in year 12.
- Based on the results of the Equivalent Uniform Annual Cost (EUAC) calculation at an 8% discount rate, with a Capital Recovery Factor (CRF) of 0.102, Alternative 1 yields a Present Value (PV) of IDR 13,655,411,431, an Equivalent Uniform Annual Cost (EUAC) of IDR 1,390,833,816.62, and an EUAC per square yard of pavement of IDR 56,648.49. These values are the lowest among all alternatives. Therefore, from an economic perspective, Alternative 1 is the most efficient option, as it has the lowest life-cycle cost and annual cost burden over the 20-year analysis period.
- Based on the integration of pavement condition analysis using the PCI method and economic evaluation using the Life Cycle Cost Analysis (LCCA) method, the most optimal maintenance strategy for the Guru Tua Road section is Alternative 1. This strategy combines periodic maintenance for segments in fair condition, rehabilitation for segments experiencing deterioration, and continuous routine maintenance. It is considered capable of maintaining pavement performance while also providing cost efficiency over the 20-year design life.

REFERENCES

[1]. Amalia, N. (2020). Evaluation of road maintenance through the integration of PCI and LCCA methods. Journal of Infrastructure, 8(2), 67–76.

[2]. Directorate General of Highways, Ministry of Public Works and Housing. (2017). Road Pavement Manual 2017. Ministry of Public Works and Housing.

[3]. Directorate General of Highways Engineering. (2021). Planning and Programming of Road Network Preservation Works.

[4]. Fahrulyanda, A. R., Burhamtoro, & Susilo, H. (2023). Evaluation of pavement damage levels and treatment using Pavement Condition Index (PCI) based on Pd 01-2016-B on Krebet–Hayam Wuruk Road, Malang Regency. Journal of Construction Engineering Management (Undergraduate Thesis Series), Polinema.

[5]. Ministry of Public Works and Housing. (2011). Regulation of the Minister of Public Works No. 13 of 2011.

[6]. Puslitbang Road and Bridge. (2016). Guidelines for Determining Pavement Condition Index (PCI). Bandung: Ministry of Public Works and Housing.

[7]. Raedi, A., Haq, A., Iskandar, D., & Hadijah, I. (2020). Performance-based road maintenance using Life Cycle Cost method (Case study: Trans-Sumatra Road, Lampung). [Journal Name], 1(1).

[8]. Rachman, D. N., & Sari, P. I. (2020). Analysis of road damage using the PCI method and 13 handling strategies (Case study: Srijaya Raya National Road, Palembang KM 8+149 to KM 9+149). Journal of Civil Engineering UNPAL, 10(1).

[9]. Rahmawati, D. (2014). Life cycle cost comparison study for rigid and flexible pavements. National Road Implementation Agency VI, Makassar.

[10]. Reherman. (2006). FHWA Highway Construction Noise Handbook. U.S. Department of Transportation.

[11]. Saputra, Y. A., & Saputra, H. (2024). Inventory of road damage at SDN 04 Damon Bengkalis using the PCI method with ArcGIS 10.8. Inovtek Civil Engineering and Applications (TEKLA), 6(1), 1–9.

[12]. Setiadji, B. (2015). Analysis of road maintenance strategies based on Life Cycle Cost Analysis (LCCA). Journal of Civil Engineering, 22(1), 45–56.

[13]. Siswanto, H., Sulistio, H., Djakfar, L., & Wicaksono, A. (2016). Road management system and pavement condition in Indonesia: A literature review. ATPW.

[14]. Stankevich, N., Qureshi, N., & Queiroz, C. (2009). Performance-based contracting for preservation and improvement of road assets.

[15]. Susanti, B., & Wirahadikusumah, R. D. (2014). Life-cycle cost research framework for national road maintenance projects using performance-based contracts.

[16]. Law of the Republic of Indonesia No. 2 of 2022. (2022). Law No. 2 of 2022.