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Integrating Multi-Stakeholder Governance, Engineering Approaches, and Bibliometric Literature Review Insights for Sustainable Regional Road Maintenance: Contribution to Sustainable Development Goals (SDGs) 9, 11, and 16

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ABSTRACT

This study analyzes the Provincial Road Improvement and Maintenance (PRIM) program in Lombok Barat, Indonesia, which integrates technical engineering frameworks with multi-stakeholder governance mechanisms to improve road maintenance performance. Using a case study approach, data were collected through official government records, complaint management systems, multi-stakeholder forum documentation, and bibliometric analysis of global research trends. Life Cycle Cost Analysis (LCCA) demonstrated that preventive maintenance under PRIM reduced total life cycle costs by 28-35% compared to reactive maintenance models. The establishment of the Road Traffic and Transportation Forum (FLLAJ) and implementation of the Anti-Corruption Action Plan (ACAP) strengthened transparency, accelerated complaint resolution within seven working days, and enhanced public trust. The PRIM model successfully aligned technical efficiency with governance innovation while directly contributing to multiple Sustainable Development Goals (SDGs) 9, 11, and 16. The findings offer practical lessons for other developing regions seeking to institutionalize integrated infrastructure governance frameworks that simultaneously optimize service quality, fiscal sustainability, and institutional accountability.

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1. INTRODUCTION

Road infrastructure plays a fundamental role in national development, regional integration, and economic growth. In developing countries such as Indonesia, road networks dominate both passenger and freight transportation, accounting for approximately 70% of goods transport and 82% of passenger travel. Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga). However, the sustainability of these road assets faces multiple challenges, including financial limitations, environmental factors, aging pavements, and fragmented administrative responsibilities, which threaten long-term serviceability and structural integrity.

Historically, road maintenance strategies in developing regions have relied heavily on reactive interventions, where maintenance activities are undertaken only after significant deterioration occurs. This reactive approach often leads to escalating repair costs, frequent rehabilitation cycles, and even premature reconstruction, placing a substantial fiscal burden on national infrastructure budgets [1,2]. Without effective preventive measures, minor pavement defects can escalate rapidly, compromising road quality, public safety, and asset longevity.

In response, many countries have adopted Life Cycle Cost Analysis (LCCA) as a framework for optimizing infrastructure maintenance. LCCA enables infrastructure managers to evaluate the total cost of ownership throughout the entire service life of road assets, supporting more cost-effective maintenance planning. Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga). By applying LCCA, governments can optimize limited resources, extend pavement lifespan, and reduce expenditures related to major rehabilitation [3-5]. Despite these technical advances, engineering solutions alone are insufficient to address broader systemic issues that continue to limit maintenance effectiveness. Governance challenges such as institutional weaknesses, lack of accountability, corruption, and limited public participation frequently obstruct the success of road maintenance programs [6].

Emerging multi-stakeholder governance models have been increasingly recognized as essential complements to technical frameworks like LCCA. These models integrate public participation, transparency mechanisms, and anti-corruption measures to improve program accountability, stakeholder engagement, and public trust [7-10]. Public involvement at the early stages of project planning ensures that community needs are reflected, while transparent processes and collaborative governance reduce corruption risks and enhance institutional performance [11,12].

In Indonesia, the Provincial Road Improvement and Maintenance (PRIM) program exemplifies the integration of technical and governance frameworks. PRIM applies LCCA-based preventive maintenance while introducing transparency measures such as the Road Traffic and Transportation Forum (Forum Lalu Lintas dan Angkutan Jalan; FLLAJ) and the Anti-Corruption Action Plan (ACAP) to strengthen accountability and stakeholder collaboration. Additionally, PRIM directly contributes to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 16 (Peace, Justice, and Strong Institutions).

Building upon previous studies (**Table 1**), this research aims to comprehensively analyze the integration of technical engineering models and multi-stakeholder governance mechanisms within the PRIM program, focusing on their combined effects on sustainability, cost efficiency, institutional capacity, and service quality in road maintenance. The novelty of this study lies in its holistic approach, which simultaneously examines both engineering and

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governance dimensions, providing valuable insights for broader applications in developing country contexts.

Table 1. Summary of previous studies on life cycle cost analysis and multi-stakeholder governance in road infrastructure maintenance.

No	Title	Ref.
1	Comparative analysis of vehicle operating cost methods: Case study: Medan-Binjai Toll Road	[3]
2	Evaluation of pavement life cycle cost analysis: Review and analysis	[13]
3	A multiple regression pavement deterioration model for national highways of Nepal	[14]
4	Integration of RAMS in LCC analysis for linear transport infrastructures: A case study for railways	[15]
5	Optimal maintenance management for deteriorating pavement infrastructure systems considering budget constraints	[16]
6	Economic evaluation of preventive maintenance for asphalt pavement using life-cycle cost analysis	[2]
7	Assessment of the comprehensive benefit of pavement maintenance measures considering resource scarcity based on life-cycle cost	[5]
8	Fit for addressing grand challenges? A process model for effective accountability relationships within multi-stakeholder initiatives in developing countries	[10]
9	Economic appraisal of road projects in countries with developing and transition economies	[17]
10	Integrated life cycle cost comparison and environment impact analysis of the concrete and asphalt roads	[4]
11	Governance challenges in road infrastructure management in developing countries	[18]
12	Strategies to promote collaborative governance regime in Indian rural road maintenance	[12]
13	Does civil society matter for natural resource governance? A comparative analysis of multi-stakeholder participation and EITI validation outcomes	[19]
14	Meaningful public accountability in collaborative infrastructure governance: Lessons from Sydney's Western Parkland City	[11]
15	Multi-system intervention optimization for interdependent infrastructure	[20]
16	Comparative analysis of the multistage exponential Markov hazard model (MUSTEM) and highway development model (HDM-4) for road management in Laos	[21]
17	Transnational multistakeholder partnerships as vessels to finance development: Navigating the accountability waters	[22]
18	Strategic initiatives for large transport infrastructure planning: Reinforcing sustainability in urban transportation through better stakeholder engagement	[23]
19	Can relational governance improve sustainability in public-private partnership infrastructure projects? An empirical study based on structural equation modeling	[24]
20	The missing ingredient for successful multi-stakeholder partnerships: Cooperative capacity	[25]
21	Obstacles and challenges in applying stakeholder analysis to infrastructure projects: Is there a gap between stakeholder theory and practice?	[9]

2. THEORETICAL FRAMEWORK

2.1. Road Infrastructure Systems and Performance

Road infrastructure serves as a critical backbone for national and regional development, facilitating the movement of goods and people while supporting economic growth. Globally, road transport carries approximately 70% of freight and 82% of passenger movement [7].

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According to Indonesia's Law No. 2 of 2022 on Roads, road infrastructure encompasses the road body, complementary structures, and supporting facilities constructed on, above, or beneath the earth's surface, excluding railways and cableways.

The performance of road infrastructure depends on its ability to provide continuous and safe serviceability throughout its design life. Road performance is typically measured through parameters such as surface roughness, skid resistance, structural integrity, and load-bearing capacity [8]. Proper maintenance is essential to sustain these performance levels and avoid premature deterioration, which can lead to costly rehabilitation or reconstruction activities.

2.2. Road Structure and Material Composition

Road structures are generally composed of several layers, each designed to distribute traffic loads efficiently while protecting the underlying subgrade and ensuring long service life. The four primary layers include:

(i) Surface Layer (Wearing Course): The topmost layer, typically made of asphalt or Portland cement concrete, designed to resist traffic wear, ensure safety through skid resistance, and protect lower layers from water infiltration.
(ii) Base Course: Positioned directly below the surface layer, usually composed of crushed stone or stabilized aggregate, this layer distributes loads and prevents deformation.
(iii) Sub-base Layer: Made of granular materials such as sand or gravel, this layer supports the base course and enhances drainage capacity.
(iv) Subgrade: The natural or prepared soil foundation that supports all the upper layers. Its strength and stability are critical for long-term pavement performance.

The typical material composition for each structural layer is summarized in **Table 2**. Meanwhile, the structural configuration of flexible and rigid pavement layers is illustrated in **Figure 1**.

In addition to material selection, the design must account for local climate conditions, traffic loading patterns, and expected maintenance schedules to ensure sustainable performance (explained in Pedoman Bidang Jalan PU in 2025 regarding Sistem Pemeliharaan Jalan Kota, Kementerian Pekerjaan Umum).

2.3. Road Deterioration and Maintenance Models

Road infrastructure is subject to continuous deterioration over time due to repeated traffic loading, environmental effects, material fatigue, and construction deficiencies. Typical deterioration forms include cracks, potholes, rutting, surface wear, subgrade settlement, and drainage failures. Without timely interventions, small defects may escalate into major structural failures, dramatically increasing maintenance costs [8].

A systematic approach to road maintenance management is essential to control deterioration rates and extend the service life of road assets. One widely adopted framework is the Plan-Do-Check-Act (PDCA) cycle, which structures the maintenance process into four iterative stages (explained in Pedoman Bidang Jalan PU in 2025 regarding Sistem Pemeliharaan Jalan Kota. Kementerian Pekerjaan Umum). The PDCA cycle applied to road maintenance management is illustrated in **Figure 2**. The detailed definitions for each phase of the PDCA cycle are presented in **Table 3**.

Through applying this cyclical framework, agencies can monitor road conditions, schedule timely interventions, and ensure that resources are allocated efficiently to achieve optimal road performance over time (explained in Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 13/PRT/M/2011 tentang Tata Cara Pemeliharaan dan Penilikan Jalan).

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Table 2. Typical Material Composition of Road Layers.

Layer	Common Materials
Surface Layer	Asphalt concrete, Portland cement concrete
Base Course	Crushed stone, stabilized aggregate
Sub-base	Granular material, sand, gravel
Subgrade	Compacted natural soil, stabilized soil

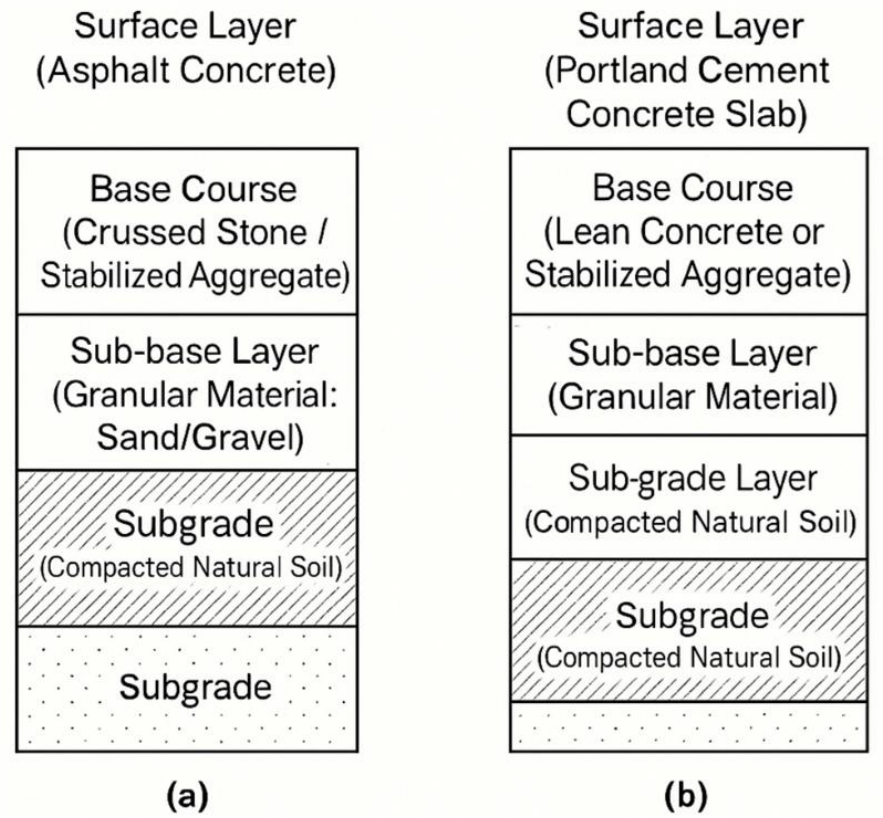

Figure 1. Standard Structure of Flexible and Rigid Pavement Layers: (a) Flexible Pavement Structure and (b) Rigid Pavement Structure.

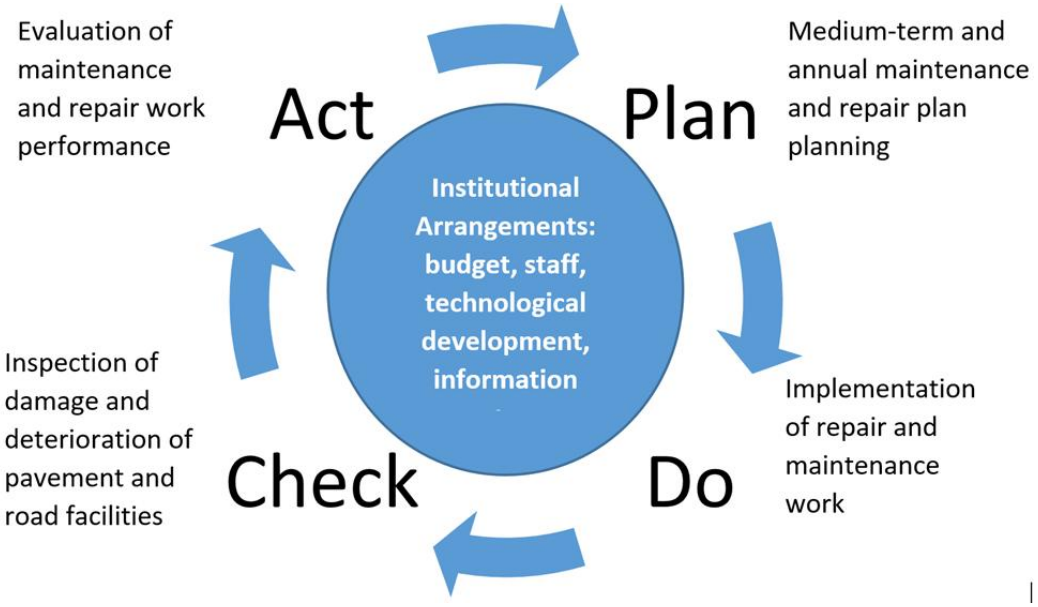

Figure 2. PDCA Cycle in Road Maintenance and Management.

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Table 3. PDCA Definition in Road Maintenance Management.

Phase	Description
Plan	Preparation of medium-term and annual maintenance plans using planning tools.
Do	Implementation of maintenance and repair works based on the prepared plans, supported by relevant institutions such as Ministry of Public Works and local governments.
Check	Conducting routine and periodic inspections after new construction or maintenance works using standard equipment such as DPS-IRI and VIS.
Act	Data analysis and evaluation of inspection results to assess the effectiveness, efficiency, and feasibility of adopted plans; integrating lessons learned into the next maintenance cycle.

2.4. Life Cycle Cost Analysis (LCCA) for Road Maintenance

LCCA is an essential economic evaluation tool for infrastructure asset management, particularly in the road sector. The LCCA framework considers the total cost of ownership across the entire service life of a road, including initial construction, routine and periodic maintenance, rehabilitation, reconstruction, and eventual decommissioning or disposal (explained in Ministry of Public Works and Public Housing in 2017 regarding Project Manajemen Manuap (PMM) PRIM Program: PMM PRIM Program amendment 4Jakarta in The Directorate General Bina Marga). This approach allows decision-makers to compare different maintenance strategies not only based on upfront costs but also considering long-term economic impacts. The conceptual framework of LCCA applied to road maintenance is illustrated in **Figure 3**.

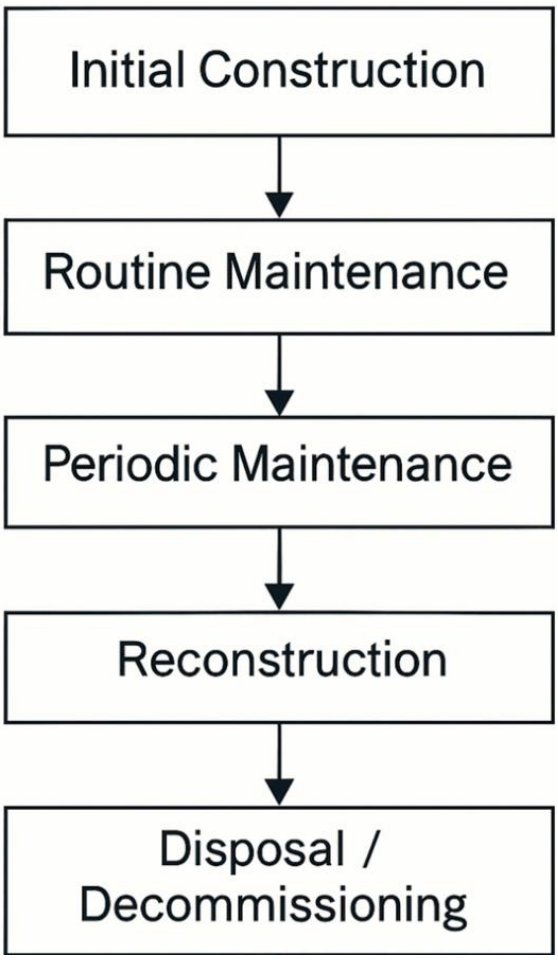

Figure 3. LCCA Conceptual Framework.

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Routine and timely preventive maintenance is emphasized in LCCA because early interventions reduce the severity of road deterioration, ultimately lowering the total cost of asset management. Postponing maintenance often leads to rapid escalation of defects, requiring significantly more expensive rehabilitation or even full reconstruction (explained in Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 13/PRT/M/2011 about Tata Cara Pemeliharaan dan Penilikan Jalan and PMM Program PRIM Amandemen 4 in 2017).

In the Indonesian regulatory framework, various maintenance activities are categorized according to their objectives and timing. **Table 4** presents typical routine maintenance activities, while **Table 5** outlines the broader classification of road maintenance works as regulated.

By applying LCCA, road agencies can allocate budgets more efficiently, prioritize preventive actions, and achieve optimal value for public investments in road infrastructure sustainability (explained in Pedoman Bidang Jalan PU in 2025 regarding Sistem Pemeliharaan Jalan Kota. Kementerian Pekerjaan Umum).

Table 4. Routine Maintenance Activities and Repair Methods.

Damage Code	Damage Category	Example Repair Methods
100	Pavement	P1-P6: Sand spreading, etc U1-U6: Pothole patching, etc K1-K6: Crack filling, etc
200	Shoulder	P1, P2, P5, P6: Sand spreading, etc U2-U4: Pothole patching, etc
300	Sidewalk	W1-W7: Resurfacing, asphalt repair, etc
400	Drainage	D1-D10: Cleaning and leveling of slopes
500	Road Equipment	F1-F9: Marker repair, signpost replacement, etc
600	Slope	B1-B7: Flow diversion, stabilization, etc
700	Emergency	E1-E7: Landslide material removal, etc
800	Structure	St1-St3: Bridge deck cleaning, etc

Table 5. Types of Road Maintenance Works.

Maintenance Type	Description
Routine Maintenance	Minor preventive works to maintain road functionality.
Periodic Maintenance	Scheduled treatments to restore road serviceability based on design projections.
Rehabilitation	Corrective actions to address unexpected severe deterioration.
Reconstruction	Complete structural rebuilding to restore long-term performance.

2.5. Multi-Stakeholder Governance in Infrastructure

Road maintenance is not solely a technical and engineering concern; it also requires coordinated governance structures that facilitate cooperation among diverse stakeholders, including government agencies, private contractors, civil society, and local communities. Multi-stakeholder governance ensures that diverse interests are balanced, public resources are utilized efficiently, and transparency is maintained throughout project cycles.

In Indonesia, the Construction Sector Transparency Initiative (CoST) and the FLLAJ serve as institutional frameworks for promoting stakeholder engagement and oversight. The FLLAJ, established under Law No. 22 of 2009, coordinates traffic and road management functions while acting as a platform for public complaints, feedback, and dialogue [7,8].

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In the PRIM program implementation, multi-stakeholder involvement played a crucial role in accelerating project delivery, addressing public concerns, and minimizing conflict during road maintenance works. Various studies have analyzed the benefits of such models for strengthening both performance and accountability. **Table 6** summarizes selected previous studies related to road maintenance governance and multi-stakeholder participation.

Table 6. Summary of Previous Studies Related to Road Maintenance and Governance.

Reference	Focus Area	Key Findings
Atikah (2021)	FLLAJ Role	Public participation improves maintenance transparency.
Gunawan & Utomo (2017)	Forum LLAJ	Institutional integration enhances maintenance efficiency.
Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding *Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4,* Jakarta by Direktorat Jenderal Bina Marga	PRIM Implementation	Multi-stakeholder models accelerate maintenance completion.

2.6. Transparency and Anti-Corruption Frameworks in Construction

Transparency is a critical factor in infrastructure development, particularly in road maintenance, where substantial public funds are allocated and multiple parties are involved in project execution. Without effective transparency mechanisms, infrastructure projects are highly vulnerable to corruption, cost overruns, low-quality work, and mismanagement.

To address these challenges, the PRIM program integrates a formal ACAP, which establishes clear reporting and monitoring systems for managing public complaints and ensuring accountability at all levels of project implementation (PMM Program PRIM Amandemen 4 in 2017). The complaint handling mechanism embedded within ACAP allows citizens to report concerns regarding potential misconduct, service deficiencies, or irregularities related to road maintenance works. The components of the ACAP complaint mechanism are summarized in **Table 7**.

Through this integrated complaint mechanism, the PRIM program fosters public trust, empowers citizens to participate actively in governance, and builds institutional capacity for corruption prevention [7,8].

Table 7. Anti-Corruption Action Plan (ACAP) Complaint Handling Mechanism in PRIM Program.

Reporting Aspect	Description	Responsible Parties
Safe and effective reporting mechanism	Reports can be submitted in writing (letters, SMS), orally (direct reports, phone calls), or online.	Public, FLLAJ
Response time	All complaints must be processed within 7 working days; the reporter's identity is protected.	Public Works Department, PIUC, Consultants, Contractors, FLLAJ
Documentation system	Each report receives a reference number and tracking status in a central database.	Complaint Management Unit
Feedback delivery	Follow-up actions are communicated back to complainants within 7 days.	Implementing Agencies

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2.7. SDG-Based Infrastructure Governance Framework

Sustainable infrastructure management directly contributes to multiple global development priorities. The United Nations' SDGs provide a universal framework that integrates economic growth, social inclusion, environmental protection, and good governance. Road maintenance activities, when managed transparently and efficiently, can contribute significantly to several SDG targets. In the context of this study, road maintenance governance and performance under the PRIM program align with three core SDG goals:

(i) SDG 9: Industry, Innovation, and Infrastructure: ensuring resilient and sustainable infrastructure systems that support inclusive industrialization and foster innovation in pavement technologies and maintenance management.
(ii) SDG 11: Sustainable Cities and Communities: promoting accessible, safe, affordable, and sustainable transportation networks within urban and regional areas, enhancing community well-being and mobility.
(iii) SDG 16: Peace, Justice, and Strong Institutions: enhancing transparency, participatory governance, and institutional accountability in public sector infrastructure programs.

The specific contributions of road maintenance programs to these SDG targets are summarized in **Table 8**.

Through its multi-stakeholder approach, transparency initiatives, and integrated technical frameworks, the PRIM program demonstrates how local road maintenance efforts can align with and support global sustainability agendas [7,8]. It is also explained in PMM Program PRIM Amandemen 4 in 2017.

Table 8. Mapping of Road Maintenance Contributions to SDGs.

SDG Goal	Road Maintenance Contribution
SDG 9	Reliable infrastructure, pavement innovation, and long-term asset management through LCCA.
SDG 11	Safer and more resilient road networks that support inclusive mobility and reduce transportation-related risks.
SDG 16	Transparent complaint systems, anti-corruption frameworks, public participation, and institutional learning mechanisms.

3. METHODS

3.1. Case Study: Indonesia's Provincial Road Improvement and Maintenance (PRIM) Program

This study adopts a case study approach to analyze the integration of multi-stakeholder governance and engineering frameworks in regional road maintenance management. The Provincial Road Improvement and Maintenance (PRIM) Program in Indonesia serves as the primary case, providing a real-world example of how technical, financial, and institutional aspects are integrated to support sustainable infrastructure delivery.

The PRIM program was launched under the coordination of the Ministry of Public Works and Housing of Indonesia, in partnership with regional governments, to strengthen road asset performance across provincial and district road networks. The program was piloted in 2017 in Lombok Barat District, West Nusa Tenggara Province, as one of the pioneering sites for implementing transparency mechanisms, multi-stakeholder forums, and community participation in road maintenance governance (explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM

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Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga). It is also explained in PMM Program PRIM Amandemen 4 in 2017.

The PRIM program introduces several key innovations in road maintenance management, including:

(i) The involvement of the FLLAJ as a formal multi-stakeholder group representing both government and non-government actors.
(ii) The application of transparent reporting and complaint handling mechanisms through the ACAP framework.
(iii) The incorporation of technical planning tools and LCCA principles to optimize road maintenance budgeting and prioritization.
(iv) Alignment with broader national and global frameworks for sustainable development, particularly supporting SDG 9, SDG 11, and SDG 16.

This case study provides valuable empirical insights for assessing how multi-stakeholder governance models can improve both road infrastructure performance and institutional accountability.

3.2. Data Sources

This study utilizes multiple data sources to capture both the technical and governance aspects of the PRIM program implementation. Data were collected from official government reports, institutional documents, monitoring records, public information portals, and media platforms related to the PRIM program activities in Lombok Barat District. The primary data sources include:

(i) Official Reports from the Ministry of Public Works and Housing (Kementerian PUPR): These include policy documents, program manuals (PMM Program PRIM Amandemen 4), and technical guidelines related to road maintenance and multi-stakeholder governance frameworks.
(ii) FLLAJ Records: Documentation of forum meetings, complaint handling logs, community participation reports, and stakeholder engagement records.
(iii) Public Works and Transportation Office of Lombok Barat District (Dinas PUPR dan Dishub Kabupaten Lombok Barat): Local government records documenting physical road maintenance progress, financial disbursement, and technical supervision reports.
(iv) Media and Public Information Platforms: Online sources such as the official Lombok Barat government website, FLLAJ social media pages (e.g., Instagram), and public media reports that reflect public feedback and complaint data [8].
(v) Legal Documents and Regulations: National laws and regulations relevant to road maintenance, governance, and transparency, including Law No. 22/2009 on Traffic and Transportation, Law No. 2/2022 on Roads, and supporting ministerial regulations (explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga).

Due to the discontinuation of the FLLAJ Lombok Barat website in 2023, supplementary data were retrieved through archived records and alternative institutional documentation sources to ensure data completeness.

This multi-source approach allows for a comprehensive assessment that integrates technical, governance, and community participation dimensions in evaluating the PRIM program's effectiveness.

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3.3. Data Analysis

The collected data were analyzed using a mixed descriptive approach to assess both the technical performance of road maintenance activities and the effectiveness of governance mechanisms implemented under the PRIM program. The analysis involved several complementary steps:

(i) Technical Performance Analysis: Road maintenance data, such as maintenance packages, scope of physical works, implementation schedules, and financial disbursements, were reviewed. The assessment focused on evaluating the completion of physical works (e.g., road segment lengths, maintenance types, backlog clearance) as reported in official government records (explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga). LCCA principles were also applied to estimate cost efficiency outcomes over the project lifecycle.

(ii) Complaint Handling Performance: Data from the FLLAJ complaint management system were reviewed to analyze the nature of public complaints, response times, types of issues reported (e.g., potholes, drainage problems, safety hazards), and institutional responsiveness [7,8]. This step captured the degree of community participation and transparency outcomes.

(iii) Governance Evaluation: Institutional documents were examined to assess the multi-stakeholder coordination process, transparency enforcement, and accountability practices under the ACAP mechanism. The degree of compliance with established reporting protocols, public disclosure, and feedback delivery was analyzed (PMM Program PRIM Amandemen 4 in 2017).

(iv) Bibliometric Trend Analysis: A bibliometric review was conducted to identify global research trends related to road maintenance, transparency, governance, and sustainability. Using databases such as Scopus or Web of Science, keyword co-occurrence mapping and publication trend visualizations were generated to contextualize the PRIM program within the global research landscape.

This comprehensive multi-dimensional analysis allows the study to integrate technical, institutional, financial, and participatory performance indicators into a unified evaluation framework.

3.4. Ethical Considerations and Transparency Protocols

The implementation of this study adheres to ethical research standards, particularly in handling governance data, public complaints, and institutional reports. Several ethical and transparency protocols were observed throughout the data collection and analysis processes:

(i) Confidentiality of Complaint Data: Public complaints obtained from FLLAJ reports and online sources were anonymized to ensure the confidentiality of individual complainants. Personal identifiers were excluded from the analysis to respect privacy rights following applicable data protection principles (PMM Program PRIM Amandemen 4 in 2017).

(ii) Institutional Permissions and Access: Official data were obtained with appropriate permissions from the relevant government agencies involved in the PRIM program, including the Ministry of Public Works and Housing, Lombok Barat District Government, and the FLLAJ secretariat. Institutional transparency frameworks allowed access to non-sensitive governance records.

(iii) Transparency Principles: The PRIM program itself operates under transparency principles embedded in its ACAP, which mandates open reporting mechanisms, public disclosure of program information, and guaranteed response timelines for public complaints [8].

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(iv) Integrity of Data Sources: All data sources were verified for accuracy and completeness before being included in the analysis. Where discrepancies were identified across different reports, triangulation techniques were employed to ensure data validity [7].
(v) Compliance with Legal and Regulatory Standards: The study conforms to national legal frameworks governing data use, public participation, and transparency, particularly Law No. 22/2009 (Traffic and Transportation) and Law No. 2/2022 (Roads).

By following these ethical and transparency protocols, the study maintains integrity in data handling, ensures protection of stakeholder interests, and strengthens the credibility of the research findings.

4. RESULTS AND DISCUSSION

4.1. Bibliometric Overview of Global Research Trends

To position this study within the global academic discourse, a bibliometric analysis was conducted, focusing on recent research trends related to road maintenance, transparency, governance, and sustainable infrastructure. Bibliometric methods allow systematic mapping of existing literature, identifying dominant research themes, highly cited studies, and global collaboration networks. The bibliometric dataset was constructed by searching the Scopus database, which is widely recognized for its comprehensive indexing of peer-reviewed literature. Previous key bibliometric studies have been well-documented, summarized in Table 9. Detailed information regarding the use of bibliometric is explained elsewhere [26-28].

The bibliometric data were retrieved from the Scopus database, using the search query: "TITLE-ABS-KEY (road AND maintenance)". The search covered the period 1906 to 2024, resulting in a total of 20,078 documents related to the road maintenance field globally.

The annual growth of publications is presented in **Figure 4**. **Figure 4** shows a sharp increase in research output over the last decade, indicating growing global attention toward road maintenance and related disciplines.

Figure 4 demonstrates that between 2016 and 2024, the volume of publications has more than doubled, with 1,757 publications recorded in 2024 alone, compared to 740 publications in 2016. This exponential growth highlights road maintenance as a rapidly expanding field of global research interest, particularly in the context of advanced maintenance technologies, infrastructure governance, and sustainability considerations. While the raw publication volume has grown substantially, thematic analysis of keywords in the dataset shows that recent studies increasingly focus on:

(i) LCCA
(ii) Pavement Maintenance Optimization
(iii) Governance, Transparency, and Accountability in Infrastructure
(iv) Sustainability and SDG Alignment in Infrastructure Asset Management
(v) Public Participation and Multi-Stakeholder Governance Models

Despite the rapid expansion of the field, empirical studies combining both engineering maintenance models and multi-stakeholder governance frameworks remain limited, particularly for developing countries such as Indonesia. This reinforces the relevance and novelty of the present study, which integrates engineering, transparency, economic evaluation, and SDG alignment in regional road maintenance governance. **Table 9** shows summary of previous bibliometric studies related to road maintenance.

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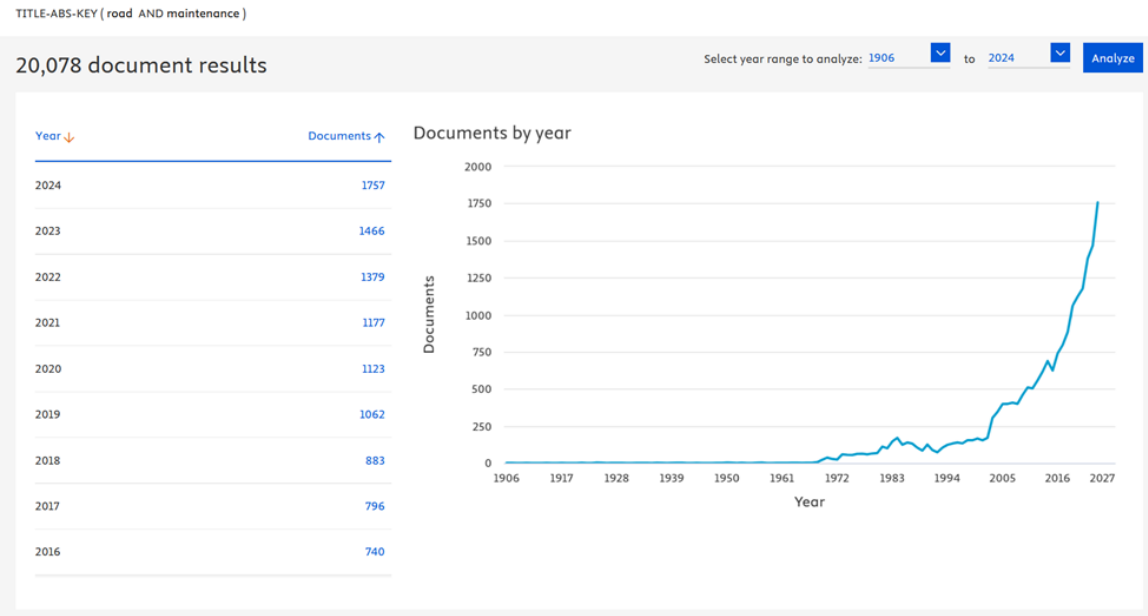

Figure 4. Global Growth of Road Maintenance Publications (1906-2024).

Table 9. Summary of Previous Bibliometric Studies Related to Road Maintenance.

No	Title	Ref.
1.	Bibliometric analysis using vosviewer with publish or perish of computational thinking and mathematical thinking in elementary school	[29]
2.	The research trend of statistical significance test: Bibliometric analysis	[30]
3.	How technology can change educational research? Definition, factors for improving quality of education and computational bibliometric analysis	[31]
4.	Chatbot artificial intelligence as educational tools in science and engineering education: A literature review and bibliometric mapping analysis with its advantages and disadvantages	[32]
5.	Correlation between meditation and religion: Bibliometric analysis	[33]
6.	Bibliometric analysis using VOSViewer with Publish or Perish of metacognition in teaching english writing to high school learners	[34]
7.	Phytoremediation with cucumis sativus: A bibliometric study	[35]
8.	Correlation of metabolomics and functional foods research in 2020 to 2023: Bibliometric analysis	[36]
9.	How to teach fraction for empowering student mathematics literacy: Definition, bibliometric, and application using digital module	[37]
10.	Nutritional research mapping for endurance sports: A bibliometric analysis	[38]
11.	Water hyacinth and education research trends from the scopus database: A bibliometric literature review	[39]
12.	Examining climate change issues for improving cross-generation awareness in 21st century agenda: A bibliometric approach	[40]
13.	Development of intelligent tutoring system model in the learning system of the Indonesian national armed forces completed with bibliometric analysis	[41]
14.	Effects of sustained deficit irrigation on vegetative growth and yield of plum trees under the semi-arid conditions: Experiments and review with bibliometric analysis	[42]
15.	Bibliometric analysis using VOSviewer with Publish or Perish of identifying local legends through project-based learning for critical thinking skills in English	[43]
16.	Use of blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic review with bibliometric analysis	[44]
17.	Bibliometric analysis of the use of biochar in an environmental law perspective	[45]
18.	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	[46]

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Table 9 (continue). Summary of Previous Bibliometric Studies Related to Road Maintenance.

No	Title	Ref.
19.	Comprehensive review on wastewater treatment using nanoparticles: Synthesis of iron oxide magnetic nanoparticles, publication trends via bibliometric analysis, applications, enhanced support strategies, and future perspectives	[47]
20.	Bibliometric analysis using VOSviewer with Publish or Perish of CEFR-based comparison of English language teaching models for communication	[48]
21.	Fourier transform infrared spectroscopy (FTIR) of pyrolysis of polypropylene microparticles and its chemical reaction mechanism completed with computational bibliometric literature review to support sustainable development goals (SDGs)	[49]
22.	Bibliometric data analysis of research on resin-based brake-pads from 2012 to 2021 using VOSviewer mapping analysis computations	[50]
23.	Bibliometric data analysis of research on resin-based brake-pads from 2012 to 2021 using VOSviewer mapping analysis computations	[51]
24.	Research trends from the scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	[52]
25.	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	[53]
26.	Hydroxyapatite as Delivery and Carrier Material: Systematic Literature Review with Bibliometric Analysis	[54]
27.	A bibliometric analysis of seed priming: Global research advances.	[55]
28.	Scientific research trends of flooding stress in plant science and agriculture subject areas (1962-2021)	[56]
29.	Bibliometric analysis for understanding “science education” for “student with special needs” using VOSviewer	[57]
30.	The use of zeolite material as a filtration media in waste treatment: Bibliometric analysis	[58]
31.	Synthesis and characterization of acetylene alcohols via alkynylation of heteroatomic aldehydes with phenylacetylene under various reaction parameters completed with spatial chemical structure, literature review, and bibliometric analysis	[59]
32.	Evaluation of assessment projects in English language education: A bibliometric review	[60]
33.	Bibliometric analysis using Vosviewer with Publish or Perish of Chinese speaking skills research	[61]
34.	Bibliometric analysis using VOSviewers with Publish or Perish of “academic reading”	[62]
35.	Bibliometric analysis on artificial intelligence research in Indonesia vocational education	[63]
36.	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021	[64]
37.	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer	[65]
38.	Artificial intelligence (AI)-based learning media: Definition, bibliometric, classification, and issues for enhancing creative thinking in education	[66]
39.	Role of coastal vegetation belts in mitigating tsunami waves: Bibliometric analysis, numerical, and spatial analysis	[67]

4.2. Stakeholder Mapping and FLLAJ Composition

The successful implementation of the PRIM program heavily relies on the collaboration between multiple stakeholders operating across various governance levels. The integration of multi-stakeholder governance was formalized through the establishment of the FLLAJ, which serves as a coordination platform to strengthen road maintenance governance, promote transparency, and increase public participation [7,8].

Based on the institutional design of the PRIM program, the primary stakeholder groups involved include:

(i) Central Government Agencies: Ministry of Public Works and Housing (Kementerian PUPR), Directorate General of Highways (Bina Marga), and national auditing institutions.

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(ii) Provincial and District Governments: Regional Public Works Departments (Dinas PUPR), Transportation Offices (Dinas Perhubungan), and Planning Agencies (Bappeda) are involved in local budgeting, planning, and project supervision.
(iii) Multi-Stakeholder Forum (such as FLLAJ): Comprising representatives from both government (executive, legislature, law enforcement) and non-government sectors (academia, professional organizations, civil society, women's groups, and disability advocates). The FLLAJ in Lombok Barat, for example, adopted a balanced composition of 50% government and 50% non-government members, with approximately 20% female representation (explained in SK Bupati Nomor 188.45/657/DISHUB/2022 tentang pembentukan forum, kelompok kerja, dan sekretariat forum lalu lintas dan angkutan jalan Kabupaten Lombok Barat Tahun 2022).
(iv) Local Communities and General Public: Citizens directly participating in complaint submission, public consultations, and monitoring activities facilitated by FLLAJ.
(v) Private Sector Contractors and Consultants: Companies involved in implementing physical maintenance works and providing technical consulting services during project execution.

The institutional arrangement of FLLAJ as a multi-stakeholder group enables:
(i) Direct community access to complaint channels.
(ii) Collective oversight of road maintenance activities.
(iii) Transparent dissemination of road maintenance plans, performance reports, and financial updates.
(iv) Enhanced coordination between technical units, governance bodies, and affected communities.

The stakeholder mapping under the PRIM program demonstrates that combining formal government structures with active community participation through FLLAJ contributes significantly to transparency, conflict resolution, and service responsiveness in road maintenance governance.

4.3. Public Complaint Handling and Responsiveness

A central innovation of the PRIM program is its structured complaint-handling mechanism, designed to encourage public participation, strengthen institutional accountability, and enhance service responsiveness in road maintenance activities. The public complaint system operates through both formal and informal reporting channels coordinated under the ACAP and facilitated by the FLLAJ as part of the program's multi-stakeholder governance framework (Atikah, 2021). It is also explained in PMM Program PRIM Amandemen 4 in 2017.

The public may submit complaints using various mechanisms, including:
(i) Written submissions (letters, formal reports)
(ii) Digital channels (SMS, email, online forms)
(iii) Verbal reports (direct visits, phone calls, public consultations)
(iv) Social media platforms (official government and FLLAJ accounts)

The institutional design allows public complaints to be submitted either directly to the FLLAJ secretariat, to the Lombok Barat District Government, or via the official regional Pusat Informasi Daerah (Public Information Center).

During the program's active implementation between 2017 and 2019, several types of complaints were documented, including:
(i) Potholes and surface damage along Jalan Pendidikan and Jalan Brawijaya.
(ii) Road safety concerns due to illegal parking by large trucks occupying road shoulders.
(iii) Drainage blockages causing localized flooding.

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(iv) Obstruction from hazardous or dead roadside trees.
(v) Public safety risks from poor visibility and inadequate signage [8].

Some interventions involved joint field inspections, immediate emergency repairs, and preventive tree removal efforts. For example, the removal of 314 dead trees was carried out across several routes in Lombok Barat to ensure user safety.

As mandated by the ACAP protocol, all public complaints were required to be acknowledged and addressed within seven working days. This accelerated response time significantly improved public trust and minimized potential conflicts during project execution.

The visual interface of the original FLLAJ complaint portal—later discontinued in 2023—is presented in **Figure 5**.

Complaint handling responsibilities were distributed across multiple actors, including:
(i) District Public Works and Transportation Offices (Dinas PUPR and Dishub)
(ii) Contractors and supervising consultants
(iii) Provincial Infrastructure Unit Coordinators (PIUC)
(iv) FLLAJ secretariat and multi-stakeholder members

This coordinated arrangement ensured that both technical and non-technical complaints could be addressed efficiently while keeping the community actively engaged in monitoring road service quality.

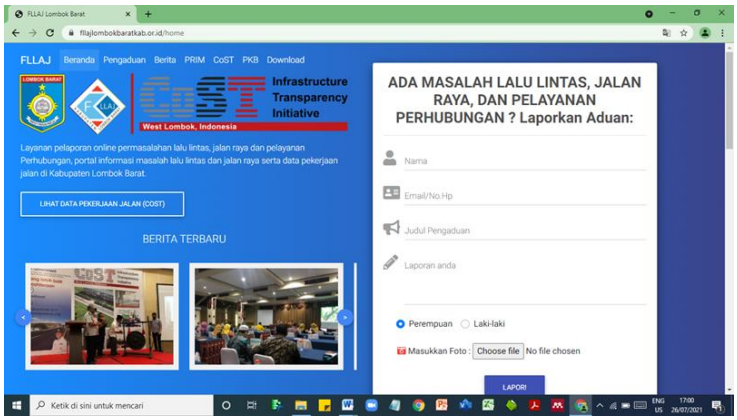

Figure 5. Screenshot of FLLAJ Lombok Barat Website.

4.4. Physical Realization of Maintenance Projects

The physical execution of maintenance works under the PRIM program in Lombok Barat District involved multiple contract packages that addressed both routine and periodic maintenance, backlog reduction, and minor rehabilitation. These maintenance packages were systematically implemented throughout 2019 as part of the program's annual work plan coordinated by the district government and supported by the FLLAJ multi-stakeholder forum. The PRIM program included various categories of maintenance activities, such as:
(i) Surface repairs (sealing, overlays, pothole patching)
(ii) Shoulder maintenance and grading
(iii) Drainage cleaning and improvement
(iv) Vegetation control (cutting and clearing roadside vegetation)
(v) Traffic safety equipment repair and replacement
(vi) Minor slope stabilization
(vii) Emergency response works

The full list of maintenance activities formally covered under PRIM is detailed in **Table 10**. In 2019, five key maintenance packages (Packages VI-X) were executed across several major

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routes in Lombok Barat. The implementation timeline and total handled road segments are summarized in **Table 11**.

Although initially designed as a year-long program, the involvement of multi-stakeholder oversight through FLLAJ, transparent reporting, and proactive institutional coordination allowed the physical maintenance works to reach full completion by August 2019, well ahead of the original year-end schedule.

The PRIM program's financing structure combined local government budget allocations (APBD) with external technical assistance from the Government of Australia. This co-financing approach strengthened both technical quality assurance and institutional learning for long-term road maintenance governance.

Table 10. Types of Road Maintenance Activities in the PRIM Program.

Maintenance Category	Specific Activities
Routine Maintenance (including Backlog and Minor Works)	Shoulder cleaning and maintenance; Drainage system maintenance; Right-of-way cleaning; Vegetation control (pruning/removal of roadside plants); Pavement maintenance (sealing, surface dressing, pothole patching); Ancillary structure maintenance; Road equipment maintenance; Grading/reshaping for unpaved and gravel roads; Slope stabilization; Emergency works
Periodic Maintenance	Overlay resurfacing; Shoulder repair; Thin asphalt resurfacing, including preventive maintenance; Surface roughening (regrooving); Crack sealing; Ancillary structure repair; Replacement/repair of missing or damaged road equipment; Road marking repainting; Pothole patching; Reshaping and blending of gravel for unpaved roads; Right-of-way cleaning
Rehabilitation and Improvement	Overlay resurfacing; Shoulder repair; Ancillary structure repair; Replacement/repair of road equipment; Re-patching; Replacement of dowel/tie bars for rigid pavements; Emergency response works; Excavation works; Embankment works; Subgrade preparation; Pavement structure works; Drainage repair/construction; Road markings; Regraveling for unpaved and gravel roads; Right-of-way cleaning
Equipment Support (Non-Road Physical Activities)	Procurement of road survey equipment; Procurement of routine maintenance equipment; Procurement of vehicles for integrated road survey and maintenance equipment
Non-Physical Support	Capacity building (training, technical guidance, coaching, etc.); Strengthening the role of FLLAJ; Implementation of Planning, Programming, and Budgeting Procedures (PPBP) or Provincial/District Road Management Systems (PRMS/KRMS)

4.5. Life Cycle Cost and Economic Efficiency Outcomes

The financial performance of road maintenance programs is directly linked to their ability to minimize total life cycle costs while maintaining optimal serviceability. The PRIM program incorporated LCCA principles to guide maintenance scheduling, budget allocations, and long-term infrastructure sustainability. In the cost categories in PRIM LCCA, the LCCA framework applied in the PRIM program includes five major cost components over the full-service life of each road segment:

(i) Initial Construction Cost
(ii) Routine Maintenance Cost
(iii) Periodic Maintenance Cost
(iv) Rehabilitation and Reconstruction Cost
(v) End-of-Life Disposal Cost

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This framework allows planners to evaluate trade-offs between early preventive actions and delayed, reactive interventions that typically result in higher long-term costs (explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga. It is also explained in PMM Program PRIM Amandemen 4 in 2017.

In the empirical LCCA outcomes in PRIM Lombok Barat, the actual project cost data from the PRIM implementation in Lombok Barat reveal the impact of timely maintenance on overall economic efficiency. **Figure 6** illustrates the cumulative cost curve across different intervention scenarios based on empirical data. However, in this paper, we will not discuss regarding the detailed ways in calculating economic evaluation. Detailed information regarding economic evaluation is explained elsewhere [68].

Table 11. Physical Realization of Road Maintenance - PRIM Program 2019.

No	Package	Road Section	Length (km)	Budget (IDR Million)	Start Date	100% Completion Date
1	Package VI	Meninting – Midang (Segment 022), Routine Maintenance + BMW (10 Sections)	4.300	27,980	January 2019	August 2019
2	Package VII	Dasan Geres – Buntage (Segment 042), Routine Maintenance + BMW (8 Sections)	6.471	22,881	January 2019	August 2019
3	Package VIII	Dasan Tereng – Sembung (Segment 026), Routine Maintenance + BMW (5 Sections)	3.200	23,500	January 2019	August 2019
4	Package IX	Gerung – Bantir (Segment 011), Routine Maintenance + BMW (5 Sections)	3.000	31,600	January 2019	August 2019
5	Package X	Keru – Suranadi (Segment 057), Routine Maintenance + BMW (7 Sections)	6.500	16,960	January 2019	August 2019

Notes: BMW = Backlog Minimum Work; All packages funded under PRIM (Provincial Road Improvement and Maintenance Program)

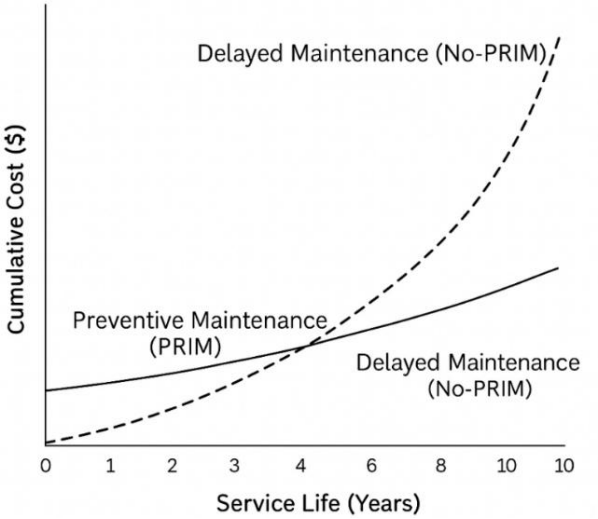

Figure 6. Life Cycle Cost Analysis Results for PRIM Road Maintenance.

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Key LCCA results are in the following:

(i) Preventive Maintenance Scenario (PRIM): Achieved up to 28-35% reduction in total life cycle costs compared to baseline no-intervention scenarios; most savings resulted from early intervention in minor defects, reducing the need for expensive rehabilitation; and backlog reduction in early stages (2017-2018) significantly lowered medium-term reconstruction needs.
(ii) Delayed Maintenance Scenario (Without PRIM): Showed steep cost escalation after year 5-6, requiring full rehabilitation of multiple segments; and, total accumulated costs rise disproportionately when minor maintenance is neglected.
(iii) Break-even Point: Within 3-4 years, the additional investments in routine and periodic maintenance are paid off by avoiding heavy rehabilitation costs in later years.

These findings validate international literature emphasizing that early-stage preventive maintenance is the most cost-effective strategy in road asset management [2,16]. For example, in the economic efficiency for regional budgets, by applying LCCA principles, we get:

(i) The Lombok Barat District Government was able to reduce long-term fiscal burdens.
(ii) Maintenance planning was integrated into multi-year budgeting frameworks.
(iii) Resources could be reallocated to additional infrastructure priorities without sacrificing service quality.

The PRIM experience demonstrates how combining LCCA with transparent governance mechanisms enhances both technical and financial sustainability of regional road networks [7,8].

4.6. Transparency Mechanism Effectiveness

Transparency mechanisms were a core component of the PRIM program design, introduced to prevent corruption, ensure public accountability, and build institutional trust in the implementation of road maintenance works. The integration of these mechanisms was achieved primarily through the ACAP framework, which operationalized transparency protocols across multiple administrative levels. The transparency system under PRIM included several institutionalized components:

(i) Public Complaint Management System: Structured reporting channels accessible to citizens for submitting complaints and receiving timely responses (Section 4.3).
(ii) Data Disclosure and Open Information: Public dissemination of maintenance plans, progress updates, financial reports, and complaint resolutions through FLLAJ meetings, online portals, and public consultations.
(iii) Monitoring and Verification Teams: Multi-stakeholder supervision teams conducting field visits, technical audits, and compliance monitoring.
(iv) Identity Protection: Safeguards protecting the confidentiality of complainants, allowing individuals to report concerns without fear of reprisal.
(v) Time-bound Response Obligations: All submitted complaints were required to be addressed within seven working days, ensuring institutional responsiveness and service recovery [8].

The division of responsibility for transparency and complaint management under the ACAP framework is summarized in **Table 12**. The transparency framework successfully improved several key performance indicators:

(i) Enhanced public trust in government agencies.
(ii) Faster resolution of road-related complaints.
(iii) Strengthened accountability among contractors and consultants.

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(iv) Reduction in potential corruption opportunities related to project supervision and budgeting.

Through these mechanisms, PRIM demonstrates how multi-level transparency and community engagement frameworks can directly improve infrastructure service quality while simultaneously advancing public sector governance reforms [7,8].

Table 12. Anti-Corruption Action Plan (ACAP) Complaint Handling Mechanism in PRIM Program.

Reporting Aspect	Description	Responsible Parties
Reporting Mechanism	Multiple reporting options: written reports (letters, forms), verbal reports (direct visits, phone calls), and digital submissions (SMS, email, online platform).	Citizens, FLLAJ Secretariat
Response Timeline	All complaints must be addressed and responded to within 7 working days.	Public Works Department (Dinas PUPR), PIUC, Consultants, Contractors
Complaint Tracking	Each complaint is assigned a reference number and entered into a centralized complaint database for tracking follow-up actions and status monitoring.	Complaint Management Unit
Feedback Delivery	The results of complaint resolutions must be communicated back to the complainant after investigation and resolution.	Implementing Agencies

4.7. Integration of Technical Engineering and Governance Outcomes

The successful implementation of the PRIM program reflects a deliberate integration of technical engineering models with governance and institutional frameworks, resulting in improved road performance, optimized resource utilization, and enhanced accountability across multiple stakeholders. The application of LCCA provided empirical evidence that preventive and timely maintenance generates substantial cost savings:

(i) Total life cycle costs were reduced by approximately 28-35% compared to reactive maintenance models (**Figure 6**).
(ii) Preventive maintenance extends service life while minimizing the need for heavy rehabilitation and reconstruction.
(iii) Early interventions addressed minor defects (potholes, drainage blockages, shoulder erosion) before escalation to major failures.
(iv) Maintenance scheduling was optimized based on real-time condition assessments and multi-year budgeting cycles.

These technical innovations promoted sustainable pavement performance and increased the resilience of road assets [2]. It is explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga.

Simultaneously, the incorporation of multi-stakeholder governance mechanisms contributed to:

(i) Establishment of FLLAJ as a legally mandated forum balancing government and non-government representation (50%/50% structure).
(ii) Operationalization of the ACAP to monitor financial transparency and ensure public accountability.
(iii) Empowerment of communities to submit complaints via formal and informal channels, with institutional guarantees for rapid response.

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(iv) Creation of inclusive decision-making platforms where diverse interests (gender, disability groups, local communities) were represented [7,8].

These mechanisms strengthened institutional trust, responsiveness, and capacity building within local governments. The integration of technical and governance domains under PRIM produced several synergistic benefits:

(i) Transparent governance supported the credibility and public acceptance of technical maintenance schedules.
(ii) Engineering models (LCCA, PDCA cycles) provided evidence-based justification for public budget allocations.
(iii) Public trust facilitated smoother project implementation, reduced conflict, and enhanced compliance among contractors and stakeholders.
(iv) Transparent reporting improved monitoring, enabling adaptive management when unforeseen challenges emerged.

Key lessons from PRIM integration are in the following:

(i) Joint engineering-governance models are critical for long-term infrastructure sustainability.
(ii) Transparency is not only a governance goal but also a technical enabler of efficient maintenance planning.
(iii) Institutionalized multi-stakeholder platforms such as FLLAJ offer scalable models for participatory governance in infrastructure sectors.

This integrated approach positions the PRIM program as a practical model for other developing countries seeking to strengthen both infrastructure performance and institutional accountability simultaneously.

4.8. Impact on Infrastructure Sustainability and Service Quality

The integration of technical engineering models with multi-stakeholder governance mechanisms under the PRIM program produced measurable improvements in both infrastructure sustainability and road service quality. The combined application of LCCA, transparent institutional frameworks, and participatory complaint handling created a self-reinforcing system for long-term road asset management.

The PRIM program generated several critical outcomes that contribute directly to the sustainability of road infrastructure:

(i) Extended Service Life of Road Assets: Preventive maintenance schedules delayed the onset of major deterioration, lengthening pavement lifespan and reducing premature reconstruction needs (as shown in Figure 6, LCCA results).
(ii) Reduced Environmental Footprint: Fewer full-depth reconstruction interventions decreased aggregate material consumption, asphalt production, and carbon emissions associated with major rehabilitation works.
(iii) Efficient Resource Allocation: LCCA-based budget planning allowed district governments to optimize financial allocations across multi-year horizons, avoiding sudden budget shocks triggered by emergency reconstruction.
(iv) Institutionalized Maintenance Culture: Local governments and public works departments adopted preventive maintenance as a norm, moving away from reactive, crisis-based approaches.

In addition to sustainability outcomes, PRIM program interventions significantly improved road serviceability for users:

(i) Reduced Surface Defects: The frequency and severity of potholes, rutting, and drainage failures were minimized through timely minor repairs.

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(ii) Improved Road Safety: Removal of roadside hazards (dead trees, blocked drainage) reduced accident risks for road users, particularly vulnerable groups such as motorcyclists and pedestrians.
(iii) Enhanced Public Satisfaction: Responsive complaint handling (within 7 working days as mandated by ACAP) increased public trust in service delivery, allowing citizens to actively participate in monitoring road conditions.
(iv) Inclusive Accessibility: Maintenance activities prioritized accessibility for all users, including gender groups, disabled persons, and rural communities often excluded from major infrastructure investments.

Resilience under Budget Constraints

By adopting this integrated model, the PRIM program demonstrated that sustainable infrastructure quality can be maintained even under constrained regional budgets, provided that preventive strategies and transparent governance are fully embedded into institutional systems.

These outcomes position the PRIM program as a replicable model for other decentralized infrastructure maintenance contexts in low- and middle-income countries, where balancing limited resources with long-term service quality remains a recurring challenge.

4.9. Institutional Learning and Capacity Building

Beyond the technical and governance outcomes, one of the most valuable long-term results of the PRIM program has been the generation of institutional learning and capacity development across government agencies, stakeholders, and local communities involved in road maintenance governance. The PRIM program served as a learning-by-doing platform that enhanced the competencies of both technical staff and governance actors through:

(i) Adoption of Evidence-Based Planning: Local public works departments improved their technical planning capacities by integrating LCCA and PDCA models into maintenance decision-making processes.
(ii) Strengthened Financial Management: Regional budgeting offices gained experience in multi-year budgeting, aligning preventive maintenance investments with long-term fiscal sustainability.
(iii) Cross-Sectoral Coordination Experience: Multi-stakeholder forums (such as FLLAJ) provided institutionalized channels for routine coordination between government, contractors, civil society organizations, and affected communities.
(iv) Legal and Policy Adaptation: Local governments developed regulatory frameworks to institutionalize transparency, anti-corruption mechanisms, and complaint management protocols.

The program incorporated a wide range of structured capacity-building activities supported by both domestic and international partners, including:

(i) Training Programs and Technical Workshops: Capacity development workshops were conducted for engineers, planners, financial officers, and governance administrators to strengthen competencies across all PRIM components.
(ii) Multi-Stakeholder Dialogue Forums: FLLAJ members engaged in regular consultations, learning sessions, and joint decision-making, fostering long-term cooperation and conflict resolution skills.
(iii) Community Engagement and Awareness Campaigns: Public outreach sessions educated citizens on how to monitor road conditions, file complaints, and participate constructively in infrastructure oversight.

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(iv) Institutional Partnerships: Technical support from international partners, such as the Government of Australia, contributed to knowledge transfer and exposure to international best practices.

Through its iterative implementation, the PRIM program cultivated a culture of continuous improvement in road maintenance governance, where both technical teams and governance institutions continuously updated procedures, adopted lessons learned, and institutionalized best practices for future program cycles.

This accumulation of institutional knowledge ensures that even after the formal PRIM program concludes, the capacity to sustain high-quality road maintenance practices remains embedded within regional and national governance structures.

4.10. Lessons for Other Developing Regions

The PRIM program experience offers transferable insights that can inform road maintenance reforms in other developing countries facing similar challenges of limited resources, decentralized governance, institutional fragmentation, and infrastructure sustainability pressures:

(i) Lesson 1: Joint Integration of Engineering and Governance. A major innovation of PRIM is its combined application of: Engineering Tools (LCCA, PDCA, Routine Maintenance Protocols; Ensuring technically sound, cost-effective, and evidence-based maintenance planning), and Governance Mechanisms (FLLAJ, ACAP, Public Complaint Systems; Ensuring accountability, transparency, public participation, and anti-corruption enforcement). Developing countries that typically approach road maintenance either as a purely technical or purely administrative issue can benefit by adopting this dual-approach integration as standard practice.

(ii) Lesson 2: Empowering Local Governments with Institutional Tools. PRIM demonstrates that subnational governments can effectively plan, finance, and execute road maintenance programs when provided with proper technical guidelines, legal mandates, capacity building, and stakeholder coordination frameworks; and Institutional learning processes gradually strengthen administrative capacity, even in low-resource contexts.

(iii) Lesson 3: Transparency and Participation Build Long-Term Public Trust. The creation of structured complaint handling, guaranteed response timelines, and active community representation, including: reduces political tensions around service delivery failures; minimizes opportunities for budget misuse; and builds public confidence in government responsiveness, even during technical failures or project delays. These outcomes serve as public trust capital, crucial for sustaining democratic governance reforms.

(iv) Lesson 4: Preventive Maintenance Reduces Long-Term Fiscal Pressure. LCCA findings confirm that early intervention dramatically reduces future rehabilitation costs; governments can stabilize infrastructure budgets by avoiding large, unpredictable repair costs; and predictable maintenance cycles improve overall budget planning and protect against sudden fiscal shocks. This is especially relevant for developing countries that operate under severe budget constraints and unstable revenue flows.

(v) Lesson 5: Replicable Model for Global SDG Implementation. By contributing directly to SDG 9 (Infrastructure Resilience), SDG 11 (Sustainable Cities), and SDG 16 (Strong Institutions).

The PRIM approach provides a scalable model for integrating the global SDG framework into practical infrastructure management programs in other developing nations.

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4.11. Alignment with SDG 9, SDG 11, and SDG 16

The PRIM program's approach to road maintenance governance demonstrates clear alignment with multiple SDGs, reinforcing its contribution not only to local infrastructure performance but also to Indonesia's global development commitments. This section maps the practical outcomes of the PRIM program to the targets of SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 16 (Peace, Justice, and Strong Institutions). The program's SDG contributions are summarized in **Table 13**.

Table 13. Mapping of Empirical SDG Contributions Based on PRIM Results.

SDG Goal	PRIM Program Contributions
SDG 9	Long-term infrastructure resilience, cost-efficient maintenance via LCCA, and institutional innovations.
SDG 11	Safer road networks, improved access and mobility, and active public participation in maintenance oversight.
SDG 16	Transparent governance, anti-corruption protocols, and strengthened institutional accountability.

In SDG 9 (Industry, Innovation, and Infrastructure), the PRIM program strengthens resilient and sustainable infrastructure by:

(i) Extending the service life of regional road networks through preventive maintenance guided by LCCA.
(ii) Introducing institutional innovation via multi-stakeholder governance frameworks such as FLLAJ.
(iii) Promoting technological adoption in maintenance planning, performance monitoring, and cost efficiency modeling [2]. It is also explained in Kementerian Pekerjaan Umum dan Perumahan Rakyat in 2017 regarding Manual Manajemen Proyek Program PRIM: PMM Program PRIM Amandemen 4, Jakarta by Direktorat Jenderal Bina Marga

In SDG 11 (Sustainable Cities and Communities), the program supports the development of inclusive, safe, and resilient communities by:

(i) Improving road accessibility and mobility for residents, businesses, and service delivery in Lombok Barat.
(ii) Incorporating safety enhancements through timely defect repairs, drainage management, and vegetation control.
(iii) Ensuring community participation in decision-making processes through complaint management systems and FLLAJ forums [7,8].

In SDG 16 (Peace, Justice, and Strong Institutions), PRIM's governance innovation directly contributes to stronger institutional capacity by:

(i) Embedding transparency, accountability, and anti-corruption safeguards through the ACAP.
(ii) Guaranteeing equal access for all citizens, including vulnerable groups, to report service deficiencies and receive corrective actions.
(iii) Institutionalizing conflict resolution processes via multi-stakeholder dialogue platforms.

The PRIM experience thus serves as an integrated model for combining engineering, governance, and sustainable development objectives in infrastructure maintenance programs. Finally, this paper adds new information regarding SDGs, as reported elsewhere [69-78].

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5. CONCLUSION

This study analyzed the Provincial Road Improvement and Maintenance (PRIM) program in Lombok Barat, Indonesia, as a comprehensive case of integrated road maintenance governance that combines technical engineering models with multi-stakeholder governance innovations. The findings provide strong evidence that both technical and institutional innovations are critical to achieving infrastructure sustainability, cost efficiency, and public accountability.

From the technical perspective, the application of LCCA demonstrated that early-stage preventive maintenance significantly reduces total life cycle costs, prevents premature deterioration, and extends the functional service life of road assets. The PRIM program achieved up to 28-35% cost savings by adopting preventive maintenance strategies, validating international best practices in infrastructure asset management.

From the governance perspective, the incorporation of multi-stakeholder forums (such as FLLAJ), public complaint handling systems, and the ACAP enhanced transparency, minimized corruption risks, and fostered public participation in road service monitoring. Institutional learning and capacity-building activities further strengthened local government competencies, enabling sustainable road maintenance programs even under budgetary constraints.

The PRIM program's holistic approach also successfully aligned with multiple SDGs, notably:

(i) SDG 9 (Industry, Innovation, and Infrastructure): through technical resilience and planning innovation.
(ii) SDG 11 (Sustainable Cities and Communities): by improving mobility, safety, and inclusiveness.
(iii) SDG 16 (Peace, Justice, and Strong Institutions): by advancing transparent, accountable, and participatory governance models.

The lessons derived from PRIM offer a practical, replicable model for other developing countries seeking to strengthen infrastructure maintenance while simultaneously addressing governance reform, fiscal sustainability, and community participation. The combined integration of technical engineering rigor with transparent governance systems is essential for ensuring both the economic efficiency and institutional legitimacy of public infrastructure investment programs.

Future research may explore the long-term institutionalization of such models across multiple sectors, further refining the scalability of combined engineering-governance frameworks for decentralized infrastructure management worldwide.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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