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BARRIERS FOR TIME, COST, AND QUALITY MANAGEMENT IN POLYMER MODIFIED ASPHALT ROAD CONSTRUCTION IN SRI LANKA

M.M. Nilanka[1], R.M.T.D. Rajapaksha[2], S.D. Gallage[3] and D.M.L.N. Bandaranayake[4]

ABSTRACT

Polymer Modified Asphalt (PMA) offers improved durability, reduced maintenance, and helps mitigate plastic waste, making it a sustainable alternative to conventional asphalt in road construction. The successful implementation of PMA in road construction depends on effective time, cost, and quality management. This study explores the unique challenges faced in PMA road projects in Sri Lanka by identifying specific barriers and proposing tailored strategies to improve project outcomes. Using a qualitative research approach, data were collected through expert interviews supported by a comprehensive literature review. This study is based on 12 semi-structured interviews with industry experts whose experience ranged from 4 to 15 years in road construction, including PMA applications. The findings highlight common barriers such as scheduling inefficiencies, supply chain disruptions, high material costs, and limited availability of skilled personnel. PMA-specific challenges, including temperature sensitivity, complex quality testing, and variability in material standards, were also identified. To address these, the study presents a matrix of 34 barriers and 15 strategies, including advanced planning, real-time tracking, value engineering, standardized protocols, and capacity-building programs. These strategies directly enhance project performance across all three dimensions of the Iron Triangle: time, cost, and quality. The research provides actionable insights for industry practitioners and policymakers to support the broader adoption of PMA, particularly in high-traffic and climate-sensitive regions.

Keywords: *Polymer Modified Asphalt; Project Management; Road Construction; Sustainable Infrastructure; Time-Cost-Quality.*

1. INTRODUCTION

Road infrastructure is crucial for socio-economic development, enabling access to markets, resources, and services. In the UK, road transport accounted for 91% of passenger travel and 67% of goods transport in 2008 (Gibbons et al., 2019), highlighting the global reliance on road networks. However, increasing traffic loads, climate

[1] Quantity Surveyor, Northern CJB Contracting LLC, Dubai, U.A.E., madushannilanka24@gmail.com
[2] Undergraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, 202668x@uom.lk
[3] Research Scholar, School of Architecture and Civil Engineering, University of Adelaide, Australia, sasanka.gallage@adelaide.edu.au
[4] Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, lakshithab@uom.lk

variability, and the environmental impact of traditional materials like asphalt pose significant challenges (Segui et al., 2023). Sustainable alternatives, such as recycled materials, are emerging as cost-effective, eco-friendly solutions. One such innovation is Polymer Modified Asphalt (PMA), which incorporates polymers, often from plastic waste, to enhance pavement durability, flexibility, and resistance to distress (Polacco et al., 2015). PMA contributes to longer road life, reduced maintenance, and plastic waste reduction (Nawela & Samaranayake, 2024). Despite its benefits, successful PMA adoption requires effective time, cost, and quality management (Walker & Kumar, 2005). This study investigates PMA implementation in Sri Lanka, identifies key barriers, and proposes strategic solutions to support the country's transition toward more sustainable and resilient road infrastructure.

2. LITERATURE REVIEW

2.1 GENERIC APPLICATIONS OF ASPHALT

Asphalt is a widely used paving material, with over 90% of European pavements utilising bituminous mixtures due to their smooth surface and rapid construction (Kowalski et al., 2016). These mixtures, composed of aggregates and bitumen, are produced via Hot Mix Asphalt (HMA), Warm Mix, and Cold Mix methods, differing by temperature requirements (Liu et al., 2017). Despite their advantages, asphalt pavements face challenges such as environmental degradation and high greenhouse gas emissions, with global asphalt production emitting approximately 46.08 million tons of CO_2 in 2007 (Shamoon et al., 2022). To improve sustainability and performance, the industry is adopting recycled aggregates and polymers. Polymers, both synthetic and natural, enhance asphalt properties but pose compatibility challenges (Alghrafy et al., 2021). The use of recycled plastics in asphalt offers a dual benefit: addressing plastic waste issues and improving pavement durability (Costa et al., 2019).

2.2 POLYMER MODIFIED ASPHALT

Plastic waste poses significant environmental challenges due to improper disposal, prompting interest in recycling plastics for asphalt modification (Dwivedi et al., 2019). Recycled polymers enhance asphalt's flexibility, durability, and mechanical properties, contributing to improved pavement performance (García-Morales et al., 2004; Behnood & Modiri Gharehveran, 2019). Various polymer types, including thermoplastic elastomers and plastomers, offer distinct benefits. Incorporation methods include dry and wet mixing, with the wet method promoting better chemical bonding (Chavez et al., 2019). This sustainable approach reduces emissions, diverts waste from landfills, and proves more cost-effective than conventional bitumen, supporting environmentally friendly road construction (Magar et al., 2022; Moughari & Daim, 2023).

2.3 POLYMER MODIFIED ASPHALT APPLICATION IN SRI LANKAN ROADS

In recent years, Sri Lanka has escalated its efforts to incorporate recycled plastic into asphalt for road construction. The Asset Group of Companies pioneered this approach, using shredded waste plastics in asphalt mixes to pave a 500 m pilot road from Ratmalana to Borupana (AGC innovate, 2021). Building on that early success, a government-backed initiative launched in late 2020 began converting the growing plastic waste stream into a raw material for roads (Kodithuwakku et al., 2023). This led to the first public road section paved with plastic-modified asphalt (Meegoda–Dampe Road, Homagama) in November 2020. The private sector also joined in 2021, Cargills partnered with AGC Innovate to resurface a Food City supermarket car park with Plastic Modified Asphalt Concrete (PMAC), consuming approximately 200,000 waste plastic bags (AGC Innovate, 2021). By 2022, the Western Province Road Development Authority signed agreements to use PMAC for provincial highways, supported by policies like compulsory plastic recycling and a forthcoming ban on single-use plastics (AGC Innovate, 2021). Recent research affirms the suitability of PMAC under local conditions, highlighting improvements in pavement strength and longevity as well as reductions in landfill waste and reliance on virgin materials (Kodithuwakku et al., 2023; Nawela & Samaranayake, 2024).

2.4 IRON TRIANGLE OF PROJECT MANAGEMENT

Project success in construction is often measured using the 'Iron Triangle' framework—balancing time, cost, and quality (Walker & Kumar, 2005). In Sri Lanka and similar developing countries, time overruns in road projects are common, making effective scheduling and monitoring essential (Mohammed, 2023). Cost management enhances resource use, minimises design changes, and reduces risks (Khan & Chan, 2023). Quality management ensures infrastructure durability, safety, and performance, reducing future maintenance needs (Kim et al., 2012). Integrating these three elements supports sustainable, resilient, and efficient road construction outcomes that align with stakeholder expectations (Wandiri & James, 2020).

2.5 TIME, COST, AND QUALITY MANAGEMENT BARRIERS IN ROAD CONSTRUCTION

Since PMA road construction is a relatively new concept, specific studies on its time, cost, and quality management challenges are limited. Hence, this study refers to barriers identified in conventional road construction projects to inform PMA applications. Literature highlights delays in material delivery, poor site management, incomplete designs, and financial constraints as common challenges (Arulvel & Widisinghe, 2022; Abeysinghe & Jayathilaka, 2022; Elamah, 2011; Khan & Chan, 2023). Ineffective stakeholder coordination, resistance to new technologies, and lack of training further affect project performance (Kim et al., 2012; El-Maaty et al., 2018). These barriers, although derived from regular road projects, provide a critical foundation to anticipate and address similar risks in PMA road construction. A detailed summary of the identified barriers and their impacts is presented in Table 1.

2.6 STRATEGIES FOR MITIGATING BARRIERS

To overcome time, cost, and quality-related barriers in road construction, existing literature on conventional road projects offers several strategies. Time-related solutions include efficient planning, risk management, and technologies like Integrated Project Delivery (IPD) and real-time tracking to minimize delays. Weather adaptation and streamlined permitting also support timely delivery (Lashof & Neuberger, 2023). Cost challenges are addressed through resource optimization, Life Cycle Costing (LCC), and lean construction to enhance value (Santos et al., 2017). Quality barriers are mitigated through assurance protocols, stakeholder engagement, and supplier agreements. These strategies, while not specific to PMA roads, provide relevant insights.

Table 1: Barriers influencing time, cost and quality management of road construction

Barriers	**Impact**			**Sources**												
	Time	**Cost**	**Quality**	**A**	**B**	**C**	**D**	**F**	**G**	**H**	**I**	**J**	**L**	**M**	**N**	**P**
Delay in delivery	✓	✓		✓		✓	✓	✓					✓		✓	✓
Shortage or unavailability	✓	✓		✓												✓
Construction mistakes	✓	✓	✓	✓		✓		✓								✓
Poor site management	✓	✓	✓	✓		✓		✓							✓	✓
Poor-quality design documents	✓	✓	✓			✓	✓	✓		✓					✓	
Delayed decision-making	✓			✓		✓		✓							✓	
Slowness in approvals	✓			✓		✓		✓								✓
Stakeholder coordination and communication	✓	✓	✓								✓	✓				
Insufficient project information	✓	✓	✓		✓		✓						✓	✓		
Financial issues	✓	✓		✓		✓									✓	✓
Unrealistic contract durations	✓	✓					✓						✓	✓		
Inadequate time for estimation and planning	✓	✓					✓			✓			✓	✓		
Lack of experience	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓		
Resistance to new technologies			✓						✓		✓					
Inadequate training			✓						✓		✓					
Lack of standardisation			✓						✓		✓					
Limited resources	✓	✓	✓						✓		✓	✓				
Ineffective quality control			✓						✓		✓					
Non-compliance			✓						✓		✓	✓				
Poor integration			✓						✓		✓	✓				
Price escalation of materials		✓			✓		✓			✓			✓	✓		
Frequent design changes	✓	✓			✓		✓			✓			✓	✓		

Barriers	Impact			Sources												
	Time	Cost	Quality	A	B	C	D	F	G	H	I	J	L	M	N	P
Poor direction of labour	✓	✓					✓			✓			✓	✓		
Poor site selection	✓	✓	✓		✓		✓						✓	✓		
Adverse weather	✓	✓		✓		✓		✓								✓

A - Abeysinghe & Jayathilaka (2022); B - Albtoush et al. (2020); C - Arulvel & Widisinghe (2022); D - Charoenngam & Sriprasert (2001); E - Elamah (2011); F - El-Maaty et al. (2018); G - Khan & Chan (2023); H - Kim et al. (2012); I - Karunasena et al. (2018); J - Koushki et al. (2005); K - Mahamid et al. (2012); L - Naveenkumar (2007); M - Negesa (2022); N - Olawale & Sun (2010)

3. RESEARCH METHODOLOGY

This study adopted a qualitative research approach to explore the barriers and strategies related to time, cost, and quality management in PMA road construction in Sri Lanka. Given the novelty of PMA technology in the country and the limited availability of experienced professionals, the qualitative approach was appropriate for capturing rich, contextual insights (Bryman et al., 2008; Ruffa & Evangelista, 2021). Semi-structured interviews were selected as the data collection method to allow flexibility in exploring emerging themes while maintaining focus on core research areas (Baxter & Jack, 2008). Respondents were selected using a convenience sampling with snowballing technique, targeting professionals with hands-on PMA experience. The final sample included 12 experts from consultancy and contracting sectors, each with over five years of general construction experience, road construction exposure, and at least one year of involvement in PMA projects. Details of the selected respondents are listed in Table 2 below.

Table 2: Profile of respondents

Respondent Code	Designation	Working Sector	Experience in Construction	Experience in Road Construction	Experience in PMA Road Construction
R1	Executive Engineer	Consultant	10	8	3
R2	Material Engineer	Consultant	8	5	1
R3	Project Manager	Contractor	12	10	5
R4	Planning Engineer	Contractor	7	6	2
R5	Executive Engineer	Consultant	6	4	2
R6	Project Manager	Contractor	8	6	2
R7	Engineer	Consultant	5	4	1

Respondent Code	Designation	Working Sector	Experience in Construction	Experience in Road Construction	Experience in PMA Road Construction
R8	Material Engineer	Contractor	9	7	3
R9	Material Engineer	Consultant	10	8	3
R10	Quantity Surveyor	Contractor	6	4	2
R11	Project Manager	Contractor	10	8	3
R12	Material Engineer	Consultant	15	12	1

Following this selection criterion ensured respondents were well-positioned to reflect on time, cost, and quality challenges in both traditional and PMA road projects. Interview data were manually analysed using manual content analysis to identify recurring patterns, themes, and strategies. This approach enabled the interpretation of varied perspectives, forming the basis for the effective implementation of PMA road projects in Sri Lanka.

4. RESULTS AND DATA ANALYSIS

This section presents findings on the use of conventional asphalt and its drawbacks, followed by the benefits of PMA. It also discusses PMA's implications on time, cost, and quality, and outlines key barriers and practical strategies identified through expert interviews to enhance implementation in Sri Lanka.

4.1 USE OF REGULAR ASPHALT CONCRETE IN SRI LANKA

4.1.1 Types and Usage Levels of Asphalt Concrete Mixes

In Sri Lanka, hot mix asphalt using 60/70 penetration grade bitumen is the predominant choice for road construction, valued for its durability and suitability for both binder and wearing courses. Industry professionals, including R1 and R5, affirm its widespread application. While hot mix asphalt remains the standard, gap-graded mixes are used for specific needs, and higher penetration grades like 80/100 are employed for applications such as bitumen emulsion production (R2). Cold mix asphalt, though less common, is essential for maintenance tasks like pothole patching, with R3 noting its practical use with CSS01 bitumen emulsion. This mix of diversity highlights the industry's flexible, performance-driven approach to material selection, optimizing durability, cost, and maintenance efficiency across Sri Lanka's road network.

4.1.2 Drawbacks of Regular Asphalt Concrete

Understanding the limitations of conventional asphalt is essential to justify the need for alternative solutions such as Polymer Modified Asphalt (PMA). These insights help frame the performance gaps that PMA technology may potentially address. Figure 1 illustrates the severity levels of selected drawbacks of conventional asphalt based on expert responses.

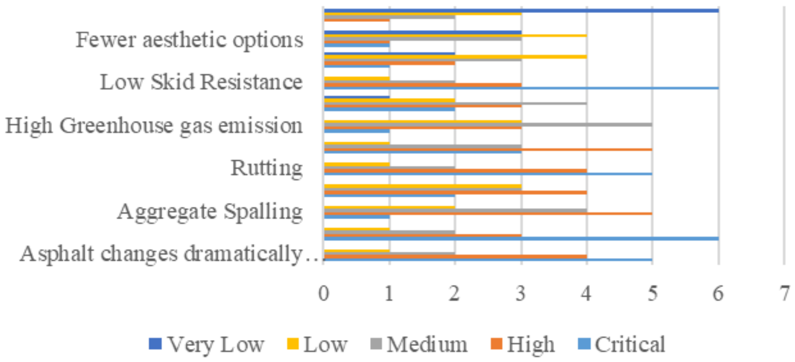

Figure 1: Impact level of drawbacks of asphalt

As shown in Figure 2, several issues are consistently rated as high or critical. "Rutting" and "Aggregate Spalling" were rated as significant challenges by multiple experts, linked to repetitive traffic loads and inadequate aggregate bonding. "High greenhouse gas emissions" and "Low skid resistance" also received medium to high concern, reflecting environmental and safety drawbacks. "Asphalt changes dramatically with temperature" emerged as a critical issue, particularly under Sri Lanka's tropical climate. Although "Fewer aesthetic options" was not widely seen as critical, the collective insights emphasize the need for enhanced materials like PMA that can overcome these performance limitations.

4.1.3 Solutions Adopted to Overcome Drawbacks of Regular Asphalt Concrete

This aimed to identify the current solutions adopted in Sri Lanka to overcome the performance limitations of conventional asphalt, as discussed in the previous section. Understanding these solutions is crucial to assess the extent to which Polymer Modified Asphalt (PMA) has been integrated into the local construction practices and to evaluate its perceived benefits relative to other alternatives. Figure 2 illustrates the various technologies currently used in Sri Lanka to address the common drawbacks of traditional asphalt, as per the respondents.

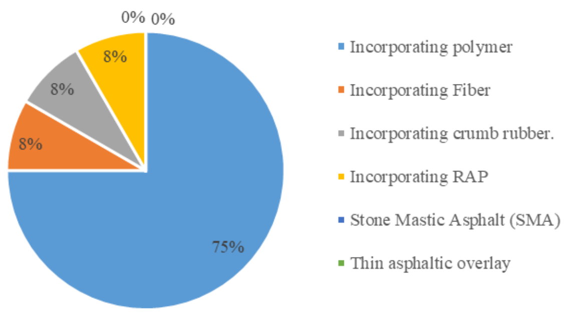

Figure 2: Solutions used in Sri Lankan context to avoid the drawbacks

As shown in Figure 3, 75% of respondents identified polymer incorporation as the primary solution adopted to enhance asphalt performance. This overwhelming preference underscores PMA's dominance in addressing issues like rutting, cracking, and aging. Other methods such as incorporating fiber, crumb rubber, and Reclaimed Asphalt Pavement (RAP) were each cited by 8% of the respondents, while Stone Mastic Asphalt (SMA) and Thin asphaltic overlays were not identified by any respondents. This trend highlights the Sri Lankan industry's strong reliance on polymer modification as the preferred performance-enhancing strategy.

4.2 Use of Polymer-Modified Asphalt

4.2.1 Benefits of Polymer Modified Asphalt (PMA) Usage

PMA offers significant advantages over conventional asphalt in enhancing road durability, performance, and lifespan. Traditional asphalt often suffers from rutting and fatigue cracking, particularly under heavy traffic and tropical climates. R3 highlights this, stating, "When using the penetration bitumen, several issues have occurred such as rutting and fatigue cracking," emphasizing the need for more resilient alternatives. PMA, classified under performance-grade (PG) bitumen, addresses these issues effectively. Grades such as PG 70-10 and PG 76-10, commonly used in Sri Lanka, provide superior resistance to temperature variations and mechanical stress. R9 notes that PMA requires careful temperature management during mixing, typically at 170–180°C. Despite its higher initial cost, PMA offers long-term value due to reduced maintenance and longer service life. As R11 states, "Polymer-based roads exhibit an extended estimated lifetime compared to conventional 60/70 bitumen-based roads," making PMA a reliable solution for sustainable and high-performance road infrastructure in Sri Lanka.

4.2.2 Polymer Types used for Asphalt Modification

This section examines the types of polymers used in PMA production in Sri Lanka, providing critical context to the material selection process and its implications for road performance and sustainability. Understanding the choice between virgin and recycled polymers is essential for evaluating the practical and environmental trade-offs involved in PMA usage. Figure 3 presents the proportion of virgin and recycled polymers used for asphalt modification.

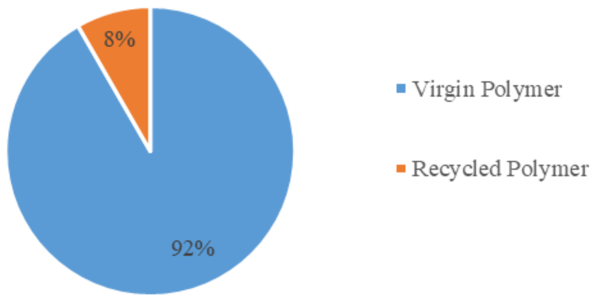

Figure 3: Polymer types used for polymer modification of asphalts in Sri Lanka

As shown in Figure 4, 92% of respondents indicated the use of virgin polymers, while only 8% reported using recycled polymers. Virgin polymers, particularly elastomers, are favoured for their consistency, flexibility, and superior performance in resisting fatigue and rutting under traffic and environmental stress. R1 highlighted that virgin polymers are preferred due to concerns over contamination in recycled materials, which affects quality and processing. However, PMA manufacturers have adopted an alternative by sourcing polymer waste directly from other manufacturers of polymer-based products. This allows access to high-quality polymer scrap free from contaminants, enabling environmental benefits by reducing landfill waste while maintaining performance standards.

4.3 BARRIERS FOR TIME, COST, AND QUALITY MANAGEMENT IN SRI LANKAN PMA ROAD CONSTRUCTION

The findings identified several unique barriers to PMA projects in Sri Lanka that arise due to the unique physical properties, handling sensitivities, and process requirements of PMA. As highlighted by respondents R1, R3, R5, R6, R8, R9, R10, and R11, the high initial cost of performance-grade bitumen and polymer additives, along with frequent price volatility, poses a major cost management barrier. Supply chain disruptions, including unreliable access to imported materials and delays in local production, often intensify these cost issues. R5 and R10 noted the temperature sensitivity of PMA during mixing and laying, which requires tight construction scheduling and coordinated material delivery to avoid cooling delays that can compromise pavement quality. In terms of quality management, R3, R6, and R9 pointed to complex and non-standardised testing protocols, as well as a shortage of trained personnel familiar with PMA technology, which negatively affects execution. Moreover, variability in testing methods and the absence of nationally standardised PMA guidelines further complicate quality assurance. The new barriers are presented in bold in Table 3 below.

4.4 STRATEGIES EMPLOYED TO OVERCOME BARRIERS IN SRI LANKAN PMA ROAD CONSTRUCTION

Key strategies include advanced planning and scheduling techniques, such as Gantt charts and critical path methods, emphasised by R6 and R10, which help anticipate potential delays and ensure timely project delivery. The integration of project management software and GPS tracking systems, highlighted by R3 and R5, enables real-time monitoring of site progress and allows for prompt decision-making to prevent schedule overruns.

Table 3: Strategies to overcome time, cost, and quality management barriers PMA road construction

Barriers	Impact			Strategy															
	Time	Cost	Quality	S1	S2	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Delay in delivery	✓	✓		✓	✓	✓											✓	
Shortage or unavailability	✓	✓					✓										✓	
Construction mistakes	✓	✓	✓								✓			✓	✓			
Poor site management	✓	✓	✓								✓		✓					
Poor-quality design documents	✓	✓	✓	✓												✓		
Delayed decision-making	✓			✓								✓						✓
Slowness in approvals	✓			✓								✓						✓
Stakeholder coordination and communication	✓	✓	✓									✓						✓
Insufficient project information	✓	✓	✓				✓			✓								
Financial issues	✓	✓					✓			✓								
Unrealistic contract durations	✓	✓		✓		✓	✓											

Barriers	Impact			Strategy															
	Time	**Cost**	**Quality**	**S1**	**S2**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
Inadequate time for estimation and planning	✓	✓		✓			✓											
Lack of experience	✓	✓	✓									✓			✓			
Resistance to new technologies			✓										✓		✓			
Inadequate training			✓												✓			
Lack of standardisation			✓													✓		
Limited resources	✓	✓	✓						✓						✓			
Ineffective quality control			✓								✓			✓				
Non-compliance			✓								✓					✓		
Poor integration			✓									✓	✓					
Price escalation of materials		✓					✓										✓	
Frequent design changes	✓	✓				✓		✓										
Poor direction of labour	✓	✓							✓			✓						
Poor site selection	✓	✓	✓	✓				✓										
Adverse weather	✓	✓				✓												
High cost PMAC materials	✓	✓					✓	✓		✓								
Price volatility of materials		✓					✓										✓	
Supply chain disruptions affecting PMAC materials	✓	✓		✓	✓												✓	
Temperature sensitivity during handling and laying	✓		✓	✓	✓												✓	
Material procurement delays	✓	✓		✓								✓						✓
Regulatory compliance in sensitive areas	✓										✓					✓		
Complexity in quality assurance and testing for PMAC			✓												✓			
Lack of trained personnel for PMAC technology			✓													✓		
Variability in PMAC quality standards and testing protocols			✓															

S1 – Advanced planning and scheduling
S2 – Use of project management software
S3 – Effective risk management
S4 – Accurate budgeting and forecasting
S5 – Value engineering
S6 – Collaborative contracting and strong partnerships
S9 – Align quality expectations
S10 – Process refinement and issue resolution
S11 – Regular inspections and audits to ensure compliance
S12 – Training programs and capacity-building

S7 – Continuous financial planning and regular budget reviews	S13 – Standardization of quality protocols and testing
S8 – Quality assurance and control systems	S14 – Diversification of supply sources
	S15 – Improved communication and coordination

Collaborative contracting and improved communication among contractors, consultants, and suppliers, as recommended by R8, R11, and R12, were seen as essential for achieving cost efficiencies and minimising procurement delays. Additionally, targeted training programs and capacity-building initiatives were advocated by R2, R6, and R9 to address the skill gaps in handling PMAC technologies. The need for standardised testing procedures and clearly defined quality protocols was also stressed to ensure consistent performance and regulatory compliance across projects. The strategies are mapped against the identified barriers in Table 3.

5. CONCLUSION AND RECOMMENDATIONS

Effective time, cost, and quality management is vital for the successful implementation of Polymer Modified Asphalt (PMA) in road construction, particularly in the Sri Lankan context. This study identifies the key barriers hindering PMA integration, such as temperature sensitivity during application, high material costs, supply chain disruptions, and complexities in quality assurance and presents targeted strategies to address them. The research confirms PMA's superior performance in terms of durability, flexibility, and resistance to environmental stresses, making it an optimal choice for high-traffic and climate-challenged regions in Sri Lanka.

A matrix linking 34 identified barriers to 15 practical strategies provides a comprehensive decision-support tool for practitioners and policymakers. Implications of this study include improved planning, procurement, training, and regulatory coordination, all of which can accelerate the safe and efficient adoption of PMA. However, the study is limited by its qualitative scope, reliance on a relatively small group of experts, and the current lack of long-term performance data on PMA roads in Sri Lanka. Future research should include quantitative validation, field performance monitoring, and integration of emerging technologies. Overall, this study provides critical insights for enhancing the sustainability and cost-effectiveness of Sri Lanka’s road infrastructure through optimised PMA application.

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