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2025TRXXEN

TECHNICAL REPORT
LOW-COST PAVEMENT SYSTEMS

TECHNICAL COMMITTEE 4.1 *PAVEMENTS*

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020–2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

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Front cover © Türkiye Çimento Sanayicileri Birliği (roller compacted concrete road in Turkey)

PIARC TECHNICAL REPORT

LOW-COST PAVEMENT SYSTEMS

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EXECUTIVE SUMMARY

2025TRXXEN

LOW-COST PAVEMENT SYSTEMS

This report delves into the concept of Low-Cost Pavement Systems, a term that is inherently subjective and complex, especially when considered within a systemic framework. Despite an extensive literature review, no universally applicable definition was found that suits diverse global contexts, spanning continents, countries, and varying social, economic, and cultural statuses. Additionally, factors such as traffic loads, climatic, and soil conditions further complicate the definition.

The primary aim of this report is to define Low-Cost Pavement Systems and establish a framework for identifying and selecting appropriate treatments. The ultimate goal is to produce a comprehensive guide outlining best practices applicable to all countries, particularly low and middle-income countries. This report does not propose specific solutions but serves as a guide that emphasizes the risks and success factors associated with Low-Cost Pavement Systems. It aims to assist in selecting the most suitable pavement type, considering factors such as material availability and environmental concerns, to construct, maintain, and operate pavements cost-effectively.

The report presents examples of selected technologies suitable for Low-Cost Pavement Systems, drawing upon the collective expertise and efforts of the authors, supported by contributions from experts worldwide. It is intended for roadway agencies, pavement engineers, technical leads, and asset managers responsible for building and developing rehabilitation programs. The proven methods presented offer potential for learning and successful implementation in other regions, with modifications as necessary based on local conditions.

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1. INTRODUCTION

The term “Low-Cost Pavement Systems” is inherently subjective and becomes increasingly complex when considered within a systemic framework. Despite a comprehensive literature review, no universally applicable definition was identified that suits diverse global contexts, spanning continents, countries, and varying social, economic, and cultural statuses. Additionally, different conditions influencing pavement structure composition, such as traffic loads, climatic, and soil conditions, add to this complexity.

This report aims to define Low-Cost Pavement Systems and establish a framework for identifying and selecting appropriate treatments. The ultimate goal is to produce a comprehensive report outlining best practices applicable to all countries, particularly low- and middle-income countries.

The purpose of this report is not to propose a solution but to serve as a guide that emphasizes the risks and success factors associated with Low-Cost Pavement Systems. It aims to assist in selecting the most suitable pavement type, considering factors such as material availability and environmental concerns, to construct, maintain, and operate pavements cost-effectively. The proven methods presented in the report offer potential for learning and successful implementation in other regions, with modifications as necessary based on local conditions.

This report presents examples of selected technologies suitable for Low-Cost Pavement Systems, drawing upon the collective expertise and efforts of the authors, supported by contributions from experts worldwide. It is intended for roadway agencies, pavement engineers, technical leads, and asset managers responsible for building and developing rehabilitation programs. We extend our best wishes for productive endeavors to all users of this report in their pursuit of creating valuable solutions.

2. LOW-COST PAVEMENT SYSTEMS

2.1. DEFINITION

Low-Cost Pavement Systems are defined as infrastructure solutions for road surfaces designed to minimize initial construction expenses and ongoing maintenance costs while ensuring adequate performance and durability. These systems typically involve the use of cost-effective materials, construction techniques, and maintenance practices without compromising safety, functionality, or longevity. The overarching goal is to achieve a balance between affordability and quality in pavement design, construction, and maintenance, as well as an approximate balance between construction and maintenance costs and the functional capability of the pavement system.

The definition of Low-Cost Pavement Systems may vary based on factors such as regional economic conditions, available resources, and specific project requirements. In low- and middle-income countries, they may be associated with pavement systems used for light traffic volumes of 20 heavy vehicles per day, similar to those typical of low-volume roads in developed countries. Conversely, in developed countries, Low-Cost Pavement Systems can be understood as standard pavement structures where low cost and high quality are achieved through innovative technologies and solutions that enable cheaper construction, ensure the same or longer service life, or reduce maintenance costs. One might assume that Low-Cost Pavement Systems are less durable and of lower quality, which is not necessarily true.

2.2. EFFICACY AND BASIC PROPERTIES

The efficacy of existing low-cost solutions depends on specific circumstances at given locations. A fundamental prerequisite for comparing solution systems is precisely defining the project plan and treatment selection criteria. The effectiveness of the resulting solution relies on a thorough understanding of the needs and available resources. In Low-Cost Pavement Systems, every effort is made to utilize the most economical resources to achieve the highest possible quality.

A Low-Cost Pavement System should ensure the following basic properties in terms of pavement performance and serviceability:

- Provide a sufficiently strong structure
- Provide a durable wearing surface
- Restore or improve pavement surface
- Protect the pavement structure and/or surface

2.2.1. Provide a Sufficiently Strong Structure

Traditionally constructed pavement structures for medium and heavy traffic consist of sub-base and base courses, as well as stabilized base, sub-base, or subgrade layers. These components are commonly employed to ensure a durable and robust structure capable of withstanding anticipated traffic loads throughout its intended lifespan.

In low-cost pavement structures for low-volume roads, some of these layers may be excluded. The design of these layers and their materials must consider specific local conditions. Engineering and pavement design optimization seek to maximize the technical and financial possibilities given the qualities of every layer and the constraints.

Under the given geological and socio-economic conditions, innovative methods may be adopted to improve the material and/or layer properties and may result in cost-effectiveness. However, these optimization procedures can also result in composite layers. Layers are subject to structural, functional, and technological principles which should be kept in mind within a given pavement structure system.

2.2.2. Provide a Durable Wearing Surface

Provide a durable wearing surface refers to creating a top layer of pavement that can withstand the stresses of traffic and environmental conditions over time. This can be utilized either independently or in conjunction with the fully constructed structure for both new and rehabilitated pavements.

Ensuring the durability of this layer is crucial for the longevity and performance of the entire pavement system.

2.2.3. Restore or Improve Pavement Surface

Surface techniques are cost-effective treatments used to restore or enhance pavement conditions to an acceptable or desired level. These techniques may address issues such as rutting, roughness, sealing to decrease porosity, improve ride quality or dust concerns.

Restoration would be carried out to address the damaged areas to return the pavement to its original condition. Enhancing the pavement's surface would include extending its lifespan or improve its performance. This might involve patching potholes, sealing cracks, seal coats, resurfacing or using materials that increase durability and skid resistance

2.2.4. Protect the Pavement Structure and/or Surface

Techniques used for preventative maintenance to prevent premature deterioration, whether structural or functional, are proactive methods employed to prevent deficiencies. These methods aim to prolong the lifespan of pavements, optimize lifecycle costs, and prepare them for subsequent rehabilitation.

2.3. COSTS

A low-cost option at the construction phase may not necessarily be a low-cost alternative during the life cycle. The typical cost of a road over its life cycle includes:

- construction cost,
- operational and maintenance cost over the life cycle,
- environmental cost.

Hence, for the purpose of this report, it is assumed that the cost is minimized by using the locally available materials and yet provide the connectivity to mobilize people and goods.

The impact of the locally available materials is not the only factor. Quality control of the works during the construction phase, the quality of the drainage system, overloaded traffic, durability, sustainability, maintenance conditions, and other factors could transform what appears to be a low-cost pavement into an expensive one, which is relative to agencies.

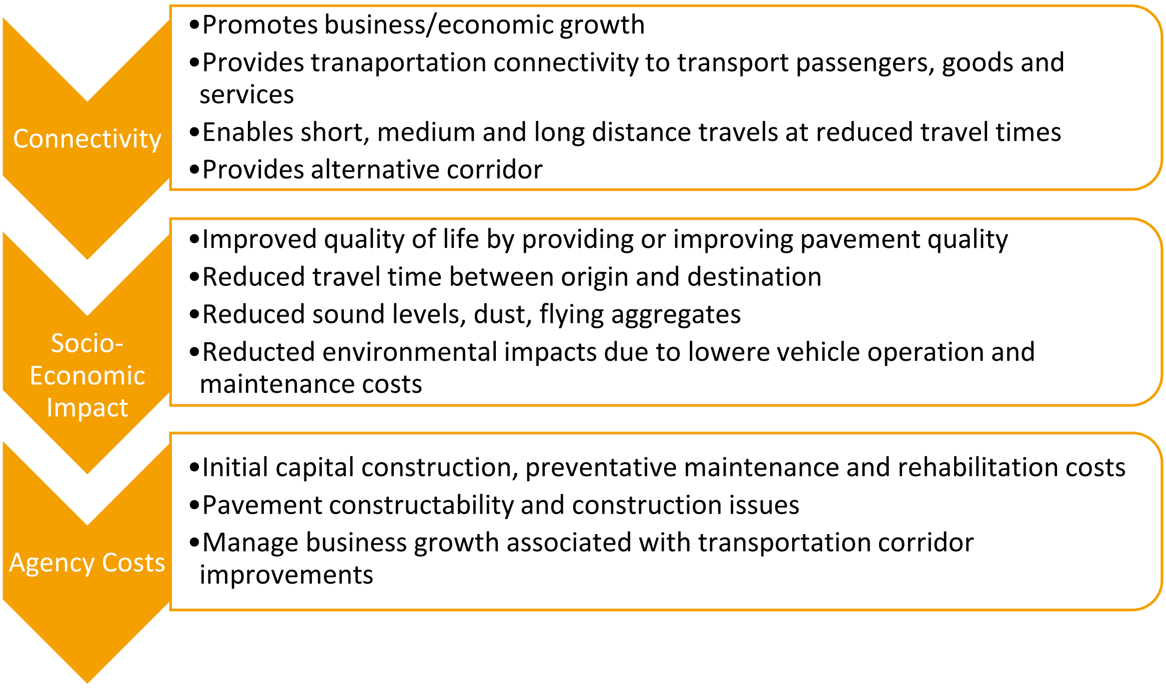
The cost depends on several factors. Table 2. 1 below lists some of these factors as a function of the relevant phase: design, construction, or operation/maintenance phase.

Phase	Cost factors
Design phase (Technical Perspective)	• The type of road • Level of traffic and its composition • The bearing capacity of the support • The design standards • The desired level of service • The service life of the design • The availability of local materials - haul distance, possibility of reuse or recycle
Design phase (Strategic Perspective)	• Definition of a perodic maintenance plan • Adoption of overall life cycle costs (construction, operations, maintenance and rehabilitation)
Construction phase	• The quality of the works • Construction techniques and equipments • Availability of desirable materials • Transport of materials
Operational/maintenance phase (Technical Perspective)	• The use of thinner layer with better performances • The operational level of traffic • The capability of reusing / recycling • Periodic maintenance including drainage or winter service
Operational/maintenance phase (Strategic Perspective)	• Strategy including the maintenance plan from the beginning of the project • Strategy of emergency intervention not generally chosen should the road use change drastically • The capability to apply necessary intervention as planned (budget constraints) • Road user comfort

Table 2. 1: Cost factors during life cycle of Low-Cost Pavement Systems

2.4. Benefits [25]

The benefits of low-cost pavements to agencies and its challenges are shown in Figure 2.1.



Connectivity

- Promotes business/economic growth
- Provides tranaportation connectivity to transport passengers, goods and services
- Enables short, medium and long distance travels at reduced travel times
- Provides alternative corridor

Socio-Economic Impact

- Improved quality of life by providing or improving pavement quality
- Reduced travel time between origin and destination
- Reduced sound levels, dust, flying aggregates
- Reducted environmental impacts due to lowere vehicle operation and maintenance costs

Agency Costs

- Initial capital construction, preventative maintenance and rehabilitation costs
- Pavement constructability and construction issues
- Manage business growth associated with transportation corridor improvements

Figure 2.1: Benefits of Low-Cost Pavement Systems

2.5. Strategy for Low-Cost Pavements Systems

2.5.1. Material Efficiency

2.5.1.1. Local Sourcing and Adaptation

Low-cost roads capitalize on locally available materials, which not only curtail transportation costs but also align with the regional landscape. For instance, in regions abundant with gravel or volcanic rock, utilizing these materials reduces the reliance on expensive imports and strengthens the road's resilience against local weather conditions.

2.5.1.2. Recycled Resources

Exploring how recycled asphalt pavement, concrete or reclaimed materials from demolition sites contribute to sustainability is vital in adopting a low-cost and sustainable alternative. Highlighting successful projects where recycled materials were employed effectively in road construction, emphasizing their performance and environmental benefits.

2.5.1.3. Soil Stabilisation Techniques

Soil stabilization methods are key for stronger roads in areas where the subgrade conditions are not as suitable. Among these techniques, in-situ soil stabilization proves transformative, particularly in challenging soil conditions. This approach involves reinforcing the local soil directly at the construction site, ensuring durable subgrade. Geotextiles, crafted from synthetic materials and strategically positioned within the soil, play a crucial role in distributing loads effectively. They enhance stability, prevent differential settlements, and fortify structural integrity, especially against moisture-induced weakening. Similarly, soil cement additives, blending existing soil with cementitious materials, significantly bolster load-bearing capacity and improve compaction, reducing vulnerability to moisture-induced expansion, cracks, shrinkage, potholes, and ruts. The details of various commonly used approaches are referred in the later section.

2.5.2. Innovative Construction Techniques

2.5.2.1. Efficient Labour and Time Reduction

Innovative approaches streamline construction processes, reducing labor requirements and time. Integration of low-cost machinery, automation, or prefabricated elements will likely expedite construction without compromising quality. To make sure the end result is positive, it will be important to use local knowledge and people's readiness to try new innovation.

2.5.3. Sustainable Practices

2.5.3.1. Permeable Pavements

Exploring the concept of permeable pavements and their role in stormwater management ensures reduced run off to water bodies. Permeable pavements not only reduce runoff but also improve water quality, emphasizing their dual benefit of sustainability and functionality as a pavement structure.

2.5.3.2. Recycled Materials in Construction

The integration of recycled materials, particularly Recycled Concrete Aggregates (RCA), within road construction stands as a pivotal step toward sustainable infrastructure development. RCA, sourced from demolished concrete structures, offers a compelling solution to address environmental concerns while maintaining and even enhancing road quality.

2.5.3.3. Cold Mix Asphalt Pavement [26]

Cold mix asphalt is a fundamental type of asphalt commonly utilized for repairs or small-scale patches. It does not necessitate heating, allowing asphalt to be placed directly onto unbound granular material, atop a well-compacted soil subgrade. Although not as robust as hot mix asphalt, it can be considerably more cost-effective and serves as an ideal option for temporary fixes when weather conditions preclude hot mix asphalt installation.

2.5.3.4. Recycled Asphalt Pavement (RAP)[27][28]

Recycled asphalt, or reclaimed asphalt pavement, is essentially old pavement that is reclaimed for re-use. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated with asphalt cement. Asphalt pavement is typically removed through milling or full-depth removal methods. Milling involves the removal of the pavement surface using a milling machine, capable of typically removing up to 80 mm thickness in a single pass. Full-depth removal entails ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. Milled or crushed RAP can be utilized in various highway construction applications, such as aggregate substitution and asphalt cement supplementation in recycled asphalt paving (hot mix or cold mix), granular base or subbase, stabilized base aggregate, or embankment and fill material.

The pursuit of a low-cost design solution is inevitably linked to the techno-economic optimization of technologies with consideration of their proper functioning as a pavement structure. One cannot just arbitrarily combine different partially advantageous technologies into the pavement structure, but the individual technologies must follow the functionality in the chosen pavement structure system.

The technologies with the high potential for the application in Low-Cost Pavement Systems are described shortly in the next section.

3. SELECTION OF APPROPRIATE LOW-COST PAVEMENT ALTERNATIVE

The section describes the steps associated with the evaluation of local conditions to arrive at the most appropriate option. The socio-economic and technical factors are also discussed.

Upon selecting viable alternatives, a thorough comparison and evaluation, considering both technical and economic aspects, are recommended for all pavement layers, commencing from the subgrade, with the overarching goal of ensuring the technical integrity of the overall pavement structure.

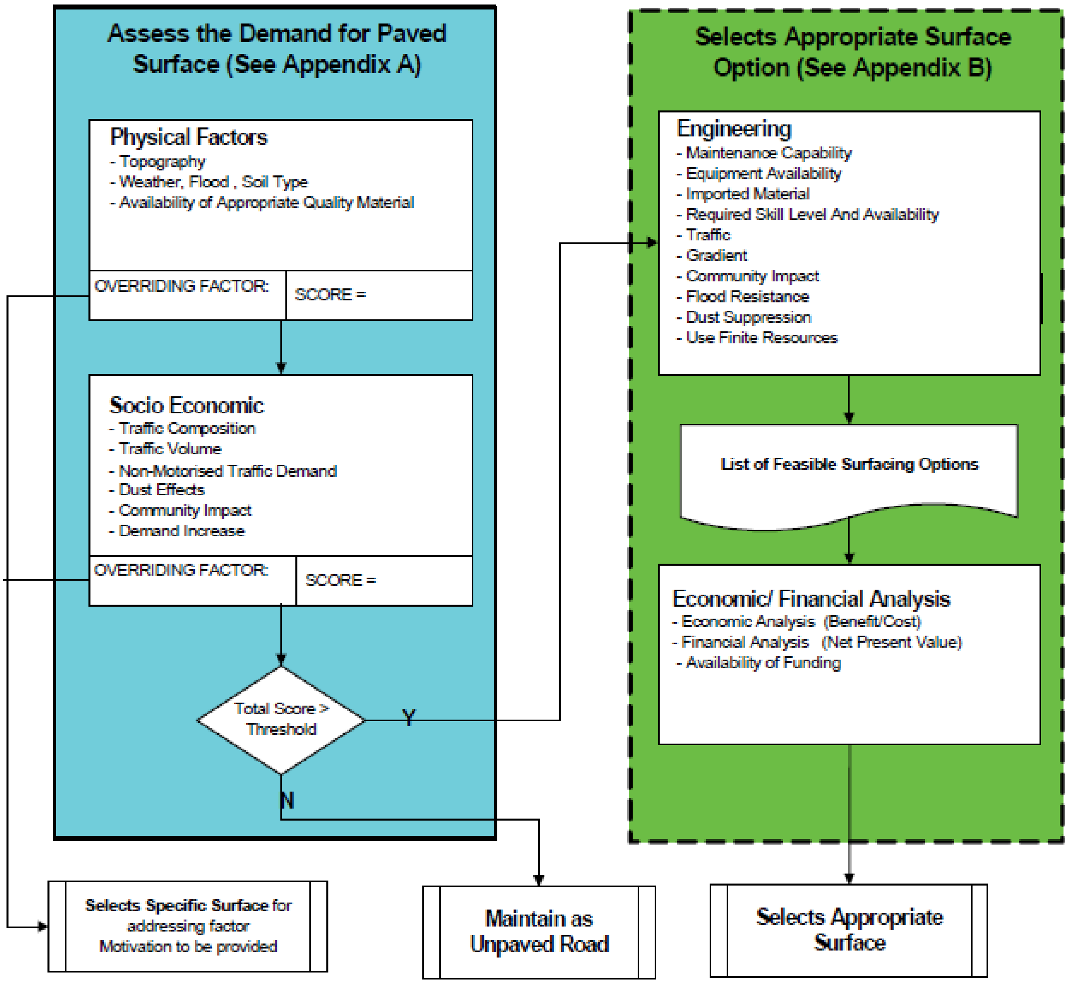


Figure 3.1. Graphical example of an analysis of surface alternatives (Reference: The World Bank, Transport Note No. TRN-33)

3.1. TECHNICAL EVALUATION

The technical requirements for proper selection of the low-cost alternatives are outlined in Figure 3.2 below.

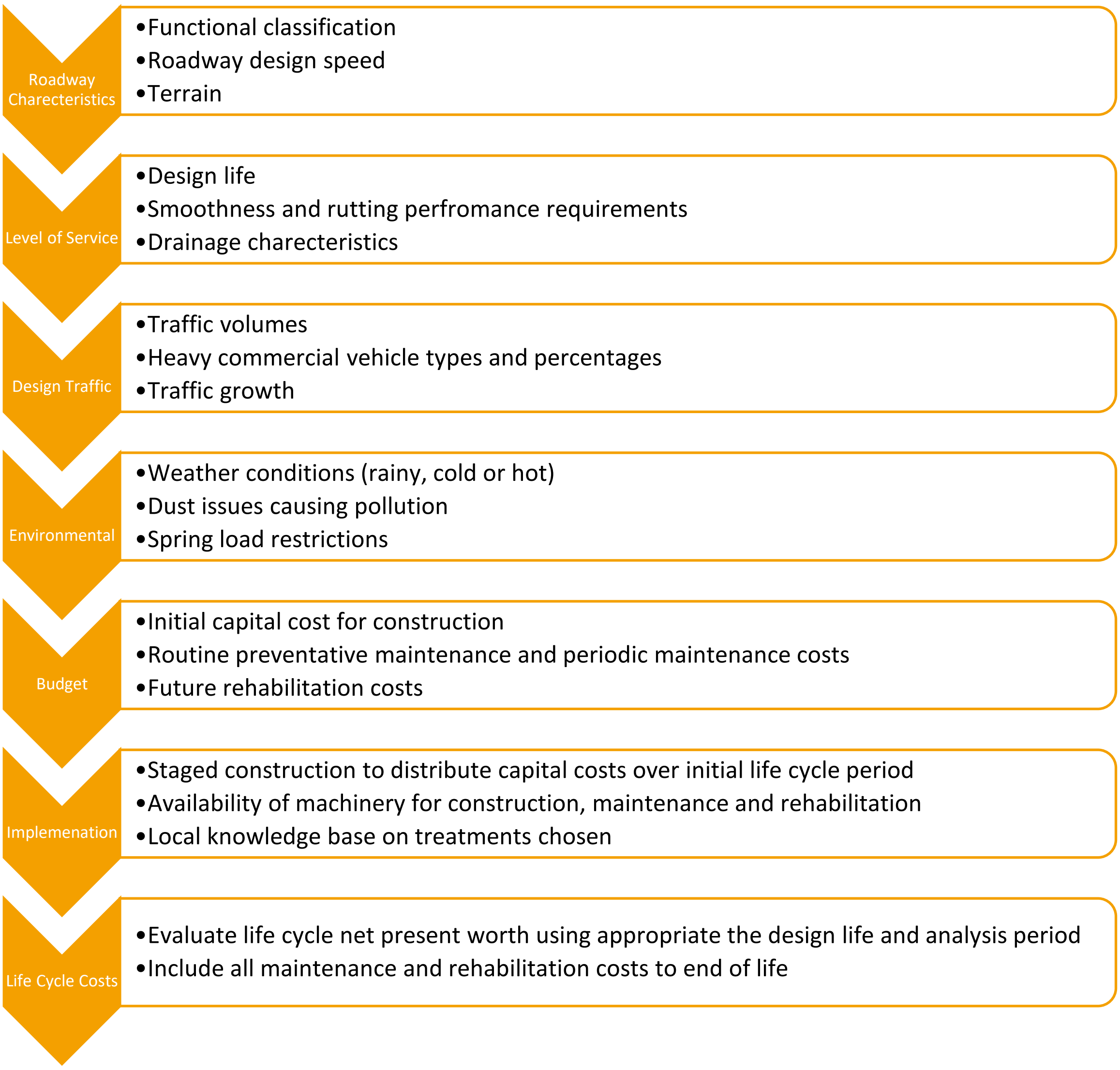


Figure 3.2: Factors governing the selection of suitable alternatives

3.2. NEED FOR CONNECTIVITY [29]

Transportation connectivity facilitates access to services and stimulates economic growth. While ensuring connectivity is a fundamental objective, the acceptable standard of service for road networks varies depending on local factors. This report focuses on low-cost pavement alternatives that offer options considering various performance parameters such as pavement strength, smoothness, and service life.

3.3. BUDGET AVAILABILITY

The strategic initiative aims to offer options for low and middle-income countries. Budget availability plays a significant role in determining whether a short-lived, smooth pavement would suffice, or if a well-built, long-lasting pavement structure with high upfront capital costs is preferable. A hybrid approach, such as staged construction, can serve as an alternative, spreading costs over time while still providing a pavement surface that meets local needs.

In situations where funds are limited and traffic volumes are very low surface upgrades are typically considered under the following circumstances:

- Low traffic volume necessitates a dust-free/smooth surface.
- Low traffic volume coupled with heavy vehicle traffic, such as on resource development roads or agricultural areas.
- Significant impact of climatic factors, such as extreme precipitation or freeze-thaw cycles.
- High maintenance costs associated with unpaved roads.

When conducting a Life Cycle Cost Analysis (LCCA), maintenance costs over the pavement's service life are generally included.

3.4. ACCEPTABLE SERVICEABILITY

Acceptable serviceability depends largely on local practices and expectations, resulting in varying definitions. For this report, serviceability is broadly categorized into two components: the structural strength needed and the acceptable functional level of service. Both these parameters depend on the desired service life, which can vary depending on project requirements and/or local practices. Structural strength directly impacts pavement service life, while functional parameters are evaluated based on set standards for international roughness index (IRI), rutting, pavement friction, etc.

3.5. STAGED APPROACHES

The staged approach to pavement construction is typically adopted for two reasons: to distribute the initial construction capital costs over its initial life cycle or to evaluate the performance and enhance the structure at a later stage based on actual needs. This approach can be optimal in low and middle-income countries as it reduces the initial capital costs. It also presents an opportunity to evaluate pavement performance, which may be a new technique to the agency, thus allowing for necessary changes before implementing the final stage of construction.

3.6. AVAILABILITY OF TECHNIQUES

The report presents alternatives available to us from research, as well as experiences from various countries. However, the list presented is not extensive enough to cover all alternatives adopted by countries, specifically low and middle-income countries. It is recommended that the agency adopting a technique assesses their access to materials, technology, equipment, and applicability as part of the planning exercise.

3.7. LIFE CYCLE COST ANALYSIS (LCCA) [6]

The report has been developed with the entire life cycle cost as a fundamental component in the implementation and management of low-cost pavements. The foundational life cycle approach should encompass initial capital expenditures along with all ensuing routine maintenance and rehabilitation costs for the analysis period. By applying a discount rate to account for inflation costs, the net present worth calculation will facilitate the ranking of options in terms of cost-effectiveness. It is imperative to meticulously examine the service life of treatments (initial construction, maintenance, and rehabilitation) as the net present worth is contingent upon these service durations.

4. LOW-COST PAVEMENT SYSTEMS – TREATMENT OPTIONS

In this report, a low-volume road represents traffic volumes of fewer than 20 heavy vehicles per day. The low-cost pavements for low volume roads are frequently used in low- and middle-income countries and they are typically constructed using in-situ soils, locally available material, and labor to reduce expenses.

Based on the surface type of the pavement, this can be broadly classified into two types:

- Unpaved roads
- Paved roads.

Unpaved roads typically mean there is no pavement structure but generally uses the existing in-situ material and a combination of approaches to either seal the surface using one or more methods mentioned below to provide a durable surface that meets the objective.

Paved roads typically consist of a pavement structure that is comprised of one or more layers and one or more materials to meet the intended pavement design life. This may follow the normal pavement design approach that is adopted by the agency. Basic types of low-cost pavements for low volume roads are:

- Earth roads (made of local soil);
- Gravel roads;
- Macadam roads;
- Soil stabilized roads;
- Surface treated roads;
- Paved roads.

4.1. EARTH ROADS [8][9]

Earth roads or compacted natural subgrade are commonly built as the first step of a staged construction process. In areas where there is no road access at all, the provision of an earth road can be a significant access improvement for local communities, thereby improving connectivity.

Earth roads are relevant when surfacing is not necessary and provide adequate support to relatively low numbers of light vehicles in areas with modest rainfall.

The soil must be shaped to shed rainwater to each side and then drained out to maintain the integrity of the road. Compaction is always necessary to ensure its stability, and it must be maintained with regular reshaping or grading.

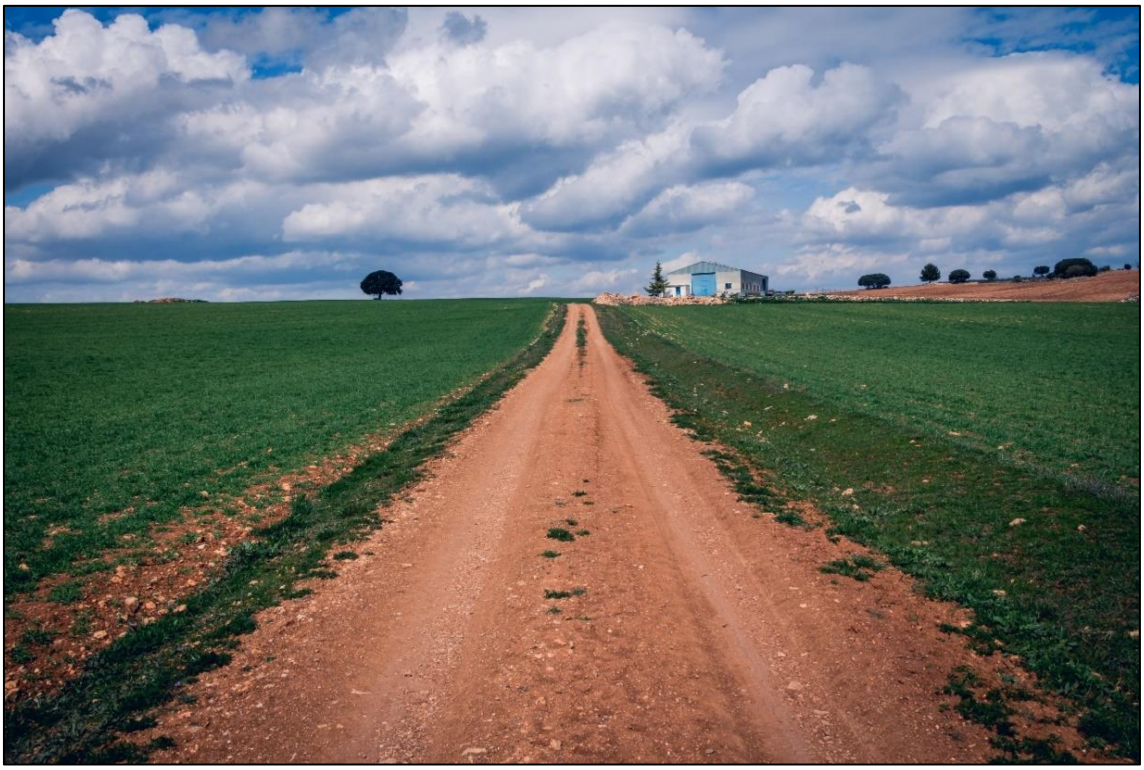


Figure 4. 1: Earth road (Reference: Freepik)

4.2. GRAVEL ROADS [10][11]

Gravel roads are generally constructed in areas where the traffic volumes are low and the percentage of heavy vehicles are limited or negligible, and the construction of paved roads is deemed expensive. Gravel roads can be suitable for providing basic all-weather access. The purpose of this will be like that of Earth Roads described above.

Gravel layer fulfills two purposes. First, a well-compacted gravel surface with a good camber prevents water from penetrating into the road and functions as a base providing strength to carry heavy traffic.

Gravel surfacing is generally used as the principal low-cost solution in many developing countries. This material provides an intermediate surface between subgrade and higher cost, often bituminous pavement. Gravel can be appropriate where suitable material is available and laid to surfacing specifications and procedures, gravel haul distances are short (usually less than 10 km), road gradients are less than about 6%, rainfall is low or moderate (less than 2,000 mm/year), traffic volume is relatively low (usually less than about 200 vehicles/day), finance and resources are available for routine maintenance and periodic regrading with addition of new material and the dust generation is not severe.

Unfortunately, these requirements may not be met in many locations. Naturally occurring lateritic and other suitable gravels tend to be rare, with good quality deposits often require hauling from far distances which can be cost prohibitive. Furthermore, gradients can be steep on low volume roads to minimize overall construction costs. When rainfall is intense and concentrated within relatively short periods, the gravel surface will be prone to be washed away. Dry season dust loss leads to the surface disintegrating due to the loss of fines, to be again washed away during the rainy season, particularly on steep sections.

Routine maintenance of gravel roads incurs relatively lower costs but has a short lifetime. However, periodic upgrading by regrading by addition of new gravel are typically required at three-to-five-year intervals. This comes with additional costs may lead to expensive maintenance. Therefore, gravel roads where it is not maintained systematically may eventually revert to earth roads.

There are environmental challenges with unrestored source borrow pits. These sources fill up with water and contribute to erosion. During the dry seasons the dust control become increasingly difficult to manage. These challenges also pose a health risk to the communities. Because of this, gravel roads face growing opposition in many countries.

Gravel surfaces have proved to be relatively costly, taking account of their need for regular replenishment, their low durability, and the rapidly declining level of service it provides to users as it deteriorates. Due consideration should be given to the aspects discussed above for successful implementation.

Figure 4. 2: Gravel Road (Reference: istockphoto)

4.3. MACADAM ROADS

The main content of a macadam type pavement layer consists of almost single size coarse aggregate of about 40- 60 mm in size. The voids in the coarse aggregate are filled with finer materials such as silt, fine sand or stone dust to increase its density and stability.

In dry areas, this process is carried out without the use of any water and referred to as dry-bound macadam. Whereas a wet-bound or water bound macadam uses water as a lubricant facilitating the movement of fines into the voids of the coarse aggregate.

Bituminous materials are also used to fill or partly fill the voids between coarse aggregates. The most common design in this respect is penetration macadam, in which the fine material is replaced with bitumen.

Figure 4. 3: Wet Mix Macadam Road (Reference: Rebuild Kerala Initiative)

4.4. SOIL STABILIZED ROADS [14][15]

Quality materials for road construction can be difficult to find in some places. Due to the prevalent geological features the subgrade may consist of soil which may be inappropriate for road building purposes. Rather than importing materials from far away, it may be more feasible to improve the properties of the local soil by mixing it with other soils or materials. Broadly, they are classified as mechanically and chemically stabilized soil.

In mechanically stabilized soil, the properties of the local soils are improved by mixing it with other soils containing the missing fractions. Sandy soils can be mixed with clay, and clayey soils with sand and gravel.

Chemical stabilization [30] of soil involves enhancing the pavement structure by altering the physical properties of the soil through the addition of a stabilizing component, typically cement, lime, bitumen, or other chemical agents, which are combined and mixed in situ. These treatments improve the overall structural strength and can facilitate movement of heavier traffic with improved service life. This may be combined with surface treatment to also provide a better ride quality in addition to a relative sound pavement structure.

Variety of techniques are available for improving the engineering properties, which are discussed below.

4.4.1. Cement Stabilized [12][13]

Cement stabilization involves creating a densely compacted mixture of soil/aggregate, cement, and water. This method finds extensive application as a cost-effective base for various infrastructures including urban and rural roads, as well as materials-handling and storage areas. The inherent benefits of cement stabilization, such as remarkable strength and durability, coupled with its initial affordability, render it a superior choice in its domain. Cement stabilized layers can be adopted on granular base and sub-base courses and on subgrade soil.

Figure 4. 4: Construction of a Cement stabilized low-volume rural road (Reference: Matinmarietta)

4.4.2. Lime Stabilized [16]

Lime-soil stabilization is the process of enhancing soil properties such as density and bearing capacity by incorporating lime, aiming to establish enduring strength over the long term. Several factors influence lime-soil stabilization, including soil composition, type of lime, lime dosage, compaction, curing duration, and additives. Lime-soil stabilized mixes prove beneficial for constructing pavement subgrade, sub-bases and base courses.

Figure 4. 5: Construction of a Lime stabilized low-volume rural road (Reference: Civilengineersforum)

4.4.3. Bitumen Stabilized/ Bitumen treated [17]

Bituminous soil stabilization is the process wherein a controlled amount of bituminous material is meticulously mixed with existing soil or aggregate material, creating a stable base or wearing surface. Bitumen enhances soil cohesion and load-bearing capacity, rendering it resistant to water. Bituminous stabilization typically employs asphalt cement, cutback asphalt, or asphalt emulsion, although the use of emulsion is preferred because of cost and environmental reasons. The choice of bitumen depends on the soil type, construction method, and prevailing weather conditions.

Figure 4. 6: Construction of a Bitumen stabilized low-volume rural road (Reference: Globalroadtechnology)

4.5. SURFACE TREATED ROADS

Surface treatment involves the application of an asphalt emulsion, cement, aggregates or a combination of one or more materials onto either an existing asphalt road or a freshly compacted granular surface. However, this can also serve as a maintenance treatment to prolong or improve the surface characterisation of pavement. These treatments are intended to safeguard the underlying pavement, restore surface characteristics, and enhance skid resistance.

4.5.1. Chip Seal / Seal Coat [18]

Aggregate seal coat encompasses various asphalt-aggregate applications, typically less than 25 mm thick, applied to various types of road surfaces. These surfaces may include primed surfaces, granular bases, existing asphalt pavement, or concrete pavements. This do not provide much of structural stability but improves rideability and prevents moisture ingress in to underlying layers. This needs to be reapplied every few years and can be susceptible to weather damage.

Figure 4. 7: Application of Chip Seal on a low-volume rural road (Reference: Driveway Experts)

4.5.2. Microsurfacing [19]

Microsurfacing bears resemblance to slurry seal in its application process. It involves the blending of water, polymer-modified asphalt emulsion, 100% manufactured aggregate, and chemical additives, all applied onto an existing asphalt concrete pavement surface. The mixture is applied using a continuous flow mixer and a spreader box, which ensures an even layer over the road surface The asphalt emulsion utilized in microsurfacing is formulated with chemical additives that facilitate its curing process without relying on sunlight or heat for evaporation. Upon application, the meticulously designed mixture undergoes a chemical transformation and swiftly solidifies to form a consistent layer of cold mix dense material, enabling traffic to resume within a few hours. The typical service life of this treatment is about 4 to 8 years.

Figure 4. 8: Application of a Microsurfacing low-volume rural road (Reference: Red Deer)

4.5.3. Slurry Seal [20]

Slurry seal comprises a blend of aggregate (crushed rock), emulsified asphalt, water, and additives, meticulously proportioned, mixed, and spread over a meticulously prepared surface. A polymer-modified system can also be employed for the same purpose, augmenting one or multiple properties of the slurry to align more effectively with specific project needs. The application of a slurry seal is executed in a singular layer using a spreader box. The slurry needs time to cure and harden, which can vary depending on weather conditions. The typical service life of this treatment is about 3 to 5 years.

Figure 4. 9: Application of a Slurry seal low-volume rural road (Reference: Bitumen6070)

4.5.4. Fog Seal [21]

A fog seal is a low-viscosity bitumen emulsion used to seal cracks less than 3 mm wide on an existing paved asphalt surface. This maintenance treatment when applied for the entire pavement surface primarily serves as an impervious sealer, slowing the rate of asphalt weathering in the underlying pavement.

A fog seal can also be used on earth roads as an anti-dust mitigation, or as a final sealing of a chip seal.

Figure 4. 10: Application of a Fog seal low-volume rural road (Reference : Rahabitumen)

4.5.5. Otta Seal

Otta Seals essentially consist of a 16 - 32 mm thick bituminous surfacing constituted of an admixture of graded aggregate from natural gravel or crushed rock in combination with relatively soft (low viscosity) binders, with or without a sand seal cover. The mechanism of application is as follows. The graded aggregate is placed on a relatively thick film of comparatively soft binder which, on rolling and trafficking, works its way upwards through the aggregate gaps. In this manner, the graded aggregate relies both on mechanical interlocking and bitumen binding for its strength – similar to a bituminous premix. Allowing traffic on the finished otta seal immediately after rolling is desirable, producing its final appearance after 4 - 8 weeks giving a “premix” like appearance. Priming of the base is normally not required. This surface type contrasts with the single sized crushed aggregate that is glued to a relatively hard (high viscosity) binders used in conventional surface dressings.

Figure 4. 11: Application of a Surface dressing low-volume rural road (Reference : Colas (top) and Northumberland Surfacing (bottom))

4.6. PAVED ROADS

There is a range of paving options that can be used, and they already were tried and proven in various countries. They could provide appropriate strength, economical and sustainable alternatives. Suitability will depend on local circumstances and experiences. These alternatives, involving the appropriate use of available materials, may be cheaper from the holistic life cycle costing approach that takes into consideration the construction, maintenance and rehabilitation costs and vehicle operating costs.

Many of these approaches can be carried out by small local enterprises using labour-based methods and light equipment. They could have lower maintenance requirements than gravel or similar roads, not only in terms of cost but also by reducing the need for heavy equipment to transport and compact, and the resulting damage to haul routes.

4.6.1. Stone Surfaces

They can be used for the construction of durable low-volume road where sources of abundant hard rock or natural smooth stones exist.

Stone paving stands out because it provides for many people, from quarry workers and chisellers to pavers. It also supports local industries, creating opportunities in tool making and other related work.

There are two types of stone pavements namely Cobblestone and Dressed stone.

4.6.1.1. Cobblestone pavement

Cobblestone pavement is made of small boulders usually river stone of about 50 – 250 mm in diameter placed side by side on a bed of sand. The stones can be arranged in a pattern or at random and compacted with plate compactors. The spaces in-between are filled with sand although in town streets it is common practice to set the stones in a concrete bedding.

It can be used for village streets, markets, rural road sections, ... Its rough surface leading to high traffic noise and vibrations is a disadvantage although it provides a durable road surface.

Figure 4. 12: Cobblestone pavement (Reference : Freepik)

4.6.1.2. *Dressed stone pavement*

Dressed stone pavement is made from extracted stone of 30 MPa minimum strength shaped and transported from rock quarries and placed on a prepared sand bed layer. It provides a smoother surface than cobblestone pavement. It is mainly used in urban areas where high traffic volumes are expected.

This pavement is among the most durable surface treatments available for roads and streets. It is commonly used on highly trafficked urban roads and streets often for its decorative and aesthetic values. Due to its exceptional durability, it is often preferred on roads where closing of traffic for maintenance works causes major traffic problems. The lifetime of this surface on high traffic roads can be estimated at 30 years.

Equally, as with concrete block pavement, stone pavement has high noise levels and vibration. For this reason, it is only used on roads and streets with low speeds. It is also an excellent surface for steep road sections.

4.6.2. Stone or concrete paving block surfaces

The stone or concrete segmented blocks surfaces are another way to prepare durable and sufficiently high-quality surfaces for low-volume road projects. They provide an ideal surfacing where excessive wear is imparted to pavement.

Segmental paving blocks usually have the thickness from 60 to 80 mm, with plain or indented sides having the top and bottom faces parallel and having either chamfered or non chamfered edges.

The advantage of the concrete pavers as compared to a concrete surface is that the initial construction costs may be lower due to the use of a wide range of materials that can be used for the supporting layers. A concrete segmental paving surface incorporating a thin bedding layer of sand can be placed upon any quality substrate, either a fully bound material such as a stabilised granular material or an unbound granular material.

It is possible to achieve satisfactory ride quality using block pavers, however the nature of the surface (small units) and the resultant placement of small areas of surfacing will, in general, produce additional unevenness compared to surfaces that are continuously laid, example asphalt pavement surfaces.

Figure 4. 13: Concrete paving block pavement (Reference :Jontypavertiles)

4.6.3. Thin bituminous surfaces [22][23]

Thin bituminous pavement surfaces are extensively employed in low-volume road networks worldwide. The bearing capacity of these pavement is predominantly provided by the unbound granular materials, with the upper bituminous surfacing serving primarily as a waterproofing layer and making minimal contribution to bending stiffness.

Typically, these pavements comprise of an upper thin bituminous layer ranging from 10 mm to 40 mm in thickness, laid over one or more layers of unbound granular material, atop a well-compacted soil subgrade. This may include hot, warm or cold mix asphalt.

Figure 4. 14: Construction of a Thin bituminous surface (Reference : asphaltmagazine.com)

4.6.4. Roller Compacted Pavements [24]

Roller-compacted concrete (RCC) derives its name from the construction method employed in its creation. It is placed using conventional or high-density asphalt paving equipment and subsequently compacted with vibratory rollers. Typically, RCC is characterized by a dry concrete mixture, sharing the same fundamental ingredients as conventional concrete: cement, water, and aggregates like gravel or crushed stone. It requires neither forming nor finishing and lacks dowels or steel reinforcing. These attributes render RCC straightforward, rapid, and cost-effective. Moreover, RCC can serve as a base for composite pavement. Its versatile applications encompass ports, intermodal facilities, industrial zones, logging sites, composting areas, storage yards, airports, arterial and local streets, as well as widened roadways and shoulders.

Figure 4. 15: Construction of a RCC low-volume rural road (Reference : Green Tech Programme)

A Turkish study [7] comparing RCC pavements to asphalt pavements reveals significant cost advantages for RCC. It compares the initial construction costs of hot-mix asphalt (HMA) and RCC pavements for the same service life, same traffic categories, same road classes and same soil classes, using official unit prices of public authorities for 2023. RCC pavements were found to be more economical for the First- and Second-Class Roads (Motorways, National Roads and Regional Roads with an Average Annual Daily Traffic (AADT) mostly between 500 and 5000). The economic efficiency increases with increasing traffic loading and decreasing bearing capacity of soils as expected, with an average of 29 % for First Class Roads and 18% for Second Class Roads. For Third Class Roads and when the AADT ≤ 100, the initials costs for HMA and RCC are comparable; when AADT ≤ 20, HMA pavements become more economical.

5. CONCLUSIONS

In todays worldwide construction sector, there is a clear balance between the cost of construction and maintaining a pavement and its performance. Low cost pavement design can offer an affordable and practical solution while still providing essential infrastructure and remaining budget friendly.

A low-cost, high-quality solution is possible by implementing an affordable design that is closely connected to optimizing the available technology in a way that also considers economical factors.

The intelligence of the resulting solution will be in the precise knowledge of the needs and possibilities available. In Low-Cost Pavement Systems, every effort is made to utilize the most cost-effective resources in design and construction in order to build to the highest possible quality, which also requires an understanding of the subtleties in innovative technologies. There are globally excellent examples of well-developed manuals and catalogues of pavement design and other construction technology documents that can be useful for decision-making, planning and implementation [1] [2].

On the one hand, regionally preferred road construction solutions are strongly based on time-tested engineering tradition, but on the other hand, requirements and the resulting responses can also change/evolve, so each case must be sensitively analyzed.

6. RECOMMENDATIONS

6.1. RECOMMENDATIONS FOR DECISIONS MAKERS

This report on Low-Cost Pavement Systems offers a methodology that can be adapted by the user to specific conditions or used as is with the suggested parameters. The three steps in the decision framework are:

1: Condition analysis for applicability of the best design solution

Evaluate the need for new construction or upgrades based on local environmental and geographic conditions; this step also has the admissibility of prevailing political or other considerations. After this step, a "go/no-go" decision can be made.

2: Applicability of the main technology

Select suitable technologies in the framework of indicated pavement as a complex system. Two general approaches are presented; a low-cost pavements for low-volume roads – Chapter 3 and a low-cost pavement techniques for heavy trafficked pavements – Chapter 4. This may be used directly or as an example for local adaptation. As a result of this step, the user will have a short list of options.

3: Economic and financial analysis

Economic and Financial analysis techniques are suggested to rank the technically feasible options selected in previous steps. The user can choose between economic and financial analysis or may use both, depending on local circumstances.

Indications on the methodology are briefly given in the Chapter 3.

6.2. RECOMMENDATIONS FOR PIARC

In a future cycle a Collection of Case Studies with succesful Low-Cost Pavement Systems could be developed.

7. GLOSSARY

Term	Definition
AADT	average annual daily traffic
HMA	hot-mix asphalt
IRI	International Roughness Index
LCCA	life cycle cost analysis
RAP	Recycled Asphalt Pavement
RCC	roller-compacted concrete

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