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Causes of Failure and Repair Strategies for Flexible Pavements in Afghanistan

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ABSTRACT

In this paper, a comprehensive review was made to explore the phenomenon flexible pavement failures within Afghanistan's road network, which consists of 3,562 Km of regional highways, 9,754 km of Provincial roads and important rural roads. It seeks to categorize the main causes of pavement failures which stem from poor design choices and material selection, inadequate drainage systems and general lack of maintenance. Overloading with heavy vehicles further worsens roads leading to structural and functional failures which are marked by distress types such as edge and fatigue cracks, potholes, and rutting. The consequences of such pavement defects are serious and threaten the safety of transportation as well as the economy. With high rates of vehicle accidents, urban, and rural roads in shambles, there is profound need for effective repair and maintenance plans. It is recommended that measures of improvement such as Repairing Potholes with Asphalt Concrete (Plant Hot Mix AC) and Excel Patch (Cold Mix Asphalt), Crack Filling (1 Layer: 12mm Aggregate + CRS-2) and (2 Layers: 19mm + 12mm Aggregate + CRS-2), fog sealing, slurry sealing, Microsurfacing, and others that are suitable to Afghanistan's weather and environment be incorporated. Also, a better pavement performance model should be suggested so as to achieve an optimal repair priority order to improve the endurance and safety of the road systems of Afghanistan.

Keywords- Afghanistan, Flexible pavements, Road infrastructure, Pavement failures, Repair strategies.

I. INTRODUCTION

Pavements serve as critical infrastructure components, designed to withstand traffic loads and environmental conditions. Structurally, they are classified into two primary types: flexible (asphalt) and rigid (concrete) pavements [1, 2]. Flexible pavements make up almost 95% of the world's roads [3]. The Afghanistan's road network comprises approximately 3,562 Km of regional highways, 4,900 Km of national highways, 9,754 km of Provincial roads 2743 km districts road and 10601 km rural (unpaved) roads [4]. Pavements play a significant role in social-economic both at the local and national level *[5]*. Countries, that are landlocked in mountainous like Afghanistan, depends mainly on road transport, which serves as the backbone of the development of the country. In this context, there is need to know about the causes for failure and suitable pavement maintenance strategies which have resulted in the loss of a huge value of the investment. While the road failure is increasing and the pavement demands more budget for treatment, the insufficient resource allocation creates more challenges for maintenance activities.

The causes of flexible pavement failure are mainly related to factors, such as traffic volume and traffic load [6], environmental factors (climate and moisture) [6], use of poor materials during construction [7], quality process [8], weak maintenance [9], pavement age [10], and subgrade [11]. *Due to these causes, the flexible pavement deteriorates both functionally and structurally, leading to localized depressions, potholes, cracking* [12], rutting, and texture loss[13]. A comprehensive review of literature was carried out for these failures and the core summaries of the selected work are shown in Table 1.

Table 1: Key factors contributing to the failure of flexible pavements, deterioration observed, underlying reasons for these issues, and actionable recommendations for improvement.

Reference	Cause of failure	Deterioration	Reason	Recommendation
[14]	Poor maintenance, design flaws	Fatigue cracks, alligator cracking, rutting	Heavy traffic, inadequate pavement thickness, poor design	Regular maintenance, improved design standards
[15]	Traffic overload	Rutting, fatigue cracking, potholes	Overloaded trucks, poor pavement design	Strengthened pavement design, traffic load management
[7]	Environmental factors	Cracking, rutting, potholes, moisture damage	Freeze-thaw cycles, high temperatures, poor drainage	limate-resilient materials, improved drainage systems
[16]	Traffic and environmental	Rutting, cracking, stripping	Heavy traffic, poor materials, environmental stress	Improved materials, better maintenance practices
[17]	Rutting due to traffic	Rutting, deformation	Heavy vehicle loads, poor subgrade materials	Improved subgrade materials, traffic load management
[18]	Rainfall impact	Moisture damage, rutting	Poor drainage, heavy rainfall	Improved drainage systems, climate-resilient materials
[19]	Temperature fluctuations	Cracking, deformation	Extreme temperature variations	Climate-resilient materials, improved design
[20]	Groundwater impact	Subgrade saturation, rutting	High groundwater table, poor drainage	Improved drainage, subgrade stabilization

There are many causes of failures for flexible pavements in Afghanistan. which is the lack of appropriate engineering practices and confidence on locally available materials that do not meet quality standards contribute significantly to premature pavement failures [21]. It must be remembered that many roads were not designed to accommodate current traffic volumes and load types, resulting in structural damage [22]. Additionally, it should be noted that temperature fluctuations can contribute to thermal cracking, while inadequate drainage systems may result in waterlogging, compromising pavement integrity [23]. Limited financial resources and lack of maintenance programs have resulted in neglected pavement surfaces, leading to accelerated wear and failure [24].

Regular conservation and repair of flexible pavements are important for ensuring road safety. Distresses such as cracking, potholes, and ruts can lead to accidents and vehicle damage [25]. The timely repairs significantly enhance the riding quality and safety of roadways [26]. Studies emphasized that effective maintenance strategies could lower overall expenditures by addressing minor issues before they increase into major problems [27, 28]. There are many common repair and rehabilitation techniques that can escalate the lifespan of flexible pavements. The proper crack sealing can significantly extend pavement life by reducing moisture damage [29]. Techniques such as Repairing Potholes Crack Filling micro-surfacing and chip sealing effectively enhance the structural capacity and extend the duration of flexible pavements [21].

The urgency of implementing such maintenance strategies becomes particularly critical in Afghanistan, where this research will is essential due to Afghanistan's heavy dependence on road networks for economic development and social connectivity. because adaptable socio-economic growth in Afghanistan is closely integrated with the country's road network development while simultaneously being impacted by extreme traffic stress, harsh environmental conditions, and poor maintenance routines, which leads to severe degradation of pavement conditions. A number of studies focus on the repair of specific road network sections, but there still remains an absence of a practical approach tailored to Afghanistan's economic difficulties, political uncertainties, and the absence of research-level studies on pavement condition monitoring situated within the Afghan framework.

The outlined directives are the focal points to structure the rest of the research:

1. Study the most significant reasons for flexible pavement failures in the country investigating the scope of traffic congestion, climatic influences, and design flaws.
2. Analyze appropriate repair and maintenance strategies with low to moderate cost implications, while also considering the regional climate.

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3. Formulate a dynamic framework for sustainable pavement management aimed to improve infrastructure resilience while also ensuring road safety.

This paper is structured around four main sections:

- Section 1: introduces the problem and its significance.
- Section 2: analyzes the causes of pavement failures.
- Section 3: examines repair strategies and their applicability.
- Section 4: Summary of findings and strategic recommendations.

The primary aim of this study is to improve the highway infrastructure of Afghanistan while aiming to strengthen the durability of pavements, thus addressing some of the outlined infrastructure gaps within the region.

II. THE CAUSES FOR FLEXIBLE PAVEMENTS FAILURE IN AFGHANISTAN

Due to several factors, flexible pavements in Afghanistan may fail. It is important to know how to address these issues. The primary factors contributing to flexible pavement failures in Afghanistan are categorized below.
2.1. Traffic Reasons
2.2. Environmental and Climatic Reasons
2.3. Underground Water Reasons
2.4. Geometric Design Reasons

2.1 Traffic Reasons

The relative volume of the traffic is one of the road problem determinants. When a road is constructed, it is anticipated that there exist foreseen traffic [30]. In a situation where they break this barrier, this puts forward an issue for the road. Other than that, the increased volume of traffic on the parapet side of the road is one of the factors creating a multitude of other issues on the surface of the road as well as on the entire structure of the road. Moreover, if a road is subjected to say almost no traffic and small vehicles, and then one day an urgent need with a large and very heavy traffic is plying on it, it has been established that it can cause cracks in the road [16] Also, other research indicates that traffic deformation of up to 100 mm causes deformations of the upper part of the covering of elastic roads. Some of the issues that are commonly experienced in Afghanistan that stem from traffic are the following: Sure! Here are the names of the types of pavement distresses caused by increased traffic load [22, 9].
1. Rutting 2. Cracking 3. Stripping 4. Potholes.

1. Rutting

Rutting is an important challenge for the preservation and performance of flexible pavements in Afghanistan [15]. It is described by development of permanent depressions in the wheel paths of the roads, which occur due to the movement of heavy vehicles over a road portion. For example, you can see the Kabul-Kandahar highway in the Fig 1, where heavy trucks transporting goods between major cities have caused severe rutting. The onset of ruts not only reduces the roadway conditions but also can cause serious threats to the safety of the motorists. Exploring the factors of rutting is critical for dealing with this problem in the aging road systems of Afghanistan.

One of the common causes of excessive rutting is traffic loading [31]. As a consequence, road construction and maintenance planning must carefully consider the vehicle mix typically found on Afghanistan's roads, which are heavily used by overloaded trucks. This overexploitation leads to excessive construction damages because pavement surfaces gradually deform with each heavy vehicle passing. Moreover, the majority of the flexible pavements in Afghanistan are also poorly designed for the vast variety of heavily deployed Wolverines. Designers overlook essential factors like the local traffic patterns and rudimentary load distributions, causing unintentional advance rupture [8].

Other reasons include the quality of subgrade, materials used, environmental conditions, and maintenance practices [32, 17].

Figure 1. Rutting along the Kabul-Kandahar road.

2. Cracking

For the affirmative traffic factors in Afghanistan, they form a notable risk as concern for flexible pavement which is one of their major issues. This greatly affects the structural frame of the roads and endangers motorists. The analysis of the type of cracking related to traffic is very important for maintenance and rehabilitation works. [33,34]. Afghanistan loses much pavements by cracks, but the very traffic related cracks are:

Fatigue Cracking: This cracking is acute in nature and it is done by heavy vehicles, particularly trucks and other commercial vehicles which have a lifting load factor. There is insufficient static weight spend between periods, so it becomes detrimental rest [35]. In Afghanistan, this type of cracking is prevalent on roads with high traffic volumes and inadequate pavement thickness. for example on the Kabul-Kandahar Highway, fatigue cracking is widespread due to the constant movement of overloaded trucks carrying goods between the two major cities. The pavement, designed for lighter loads, cannot withstand the repeated stress [15].

Alligator Cracking: Alligator cracking is frequently associated with chronic fatigue and overloading bottom-up breaking from alligator cracks that gets worse with the rest beats from big trucks. Poor drainage and no major power may aggravate the cracks even further [36]. Alligator cracking is common on roads leading to agricultural and mountain areas. Heavy trucks transporting crops overload the pavement, while poor drainage systems allow water to seep into the subgrade, weakening the base layer [37].

Figure. 2. A Road in Paktia has cracks and potholes due to its poor drainage system.

Transverse Cracking: Such cracks can arise as counterpart of other parts of the structure expansion or squeezing. Apart from the traffic context, transverse cracks come from heavy vehicles and, in conjunction to other factors, result in the stress factors cracking from top down [7].for example on the Salang Pass Highway, which connects northern Afghanistan to Kabul, transverse cracking is a major issue. The high altitude and extreme temperature variations between day and night cause the asphalt to expand and contract. Heavy trucks carrying goods over the pass further stress the pavement, leading to transverse cracks that worsen over time [38]. These cracks allow water infiltration, accelerating pavement deterioration [39].

Longitudinal Cracking: This form is the counterpart of transverse cracking where expansion is the dominating factor. It is most severe when caused due to moderate materials being placed as a flexible layer in chronic load zones as an infrastructure level. for example on the Herat-Kandahar Road, longitudinal cracking is prevalent due to the use of low-quality materials during construction [15]. The road, which serves as a major trade route, experiences heavy truck traffic, causing the pavement to crack along its length [7]. In some sections, the cracks are so severe that they have developed into potholes, posing a significant risk to vehicles and increasing travel time[26].

3. Stripping

The failure of bond in flexible pavements is particularly salient in the context of Afghanistan’s roads, as the increasing heavy traffic loads are adding tremendous strain on the existing pavements[40]. It occurs when the bond between the asphalt binder and the aggregate material is lost, and this leads to many different types of pavement distress. Below are some points describing how traffic loads contribute to stripping failure[41].

Aggressive Traffic Loads: Trade activities in Afghanistan incorporates heavy traffic ranging from bigger trucks hauling goods to military transports [42]. For example, on the construction and development of (Kabul – Jalalabad Road), holds importance as a logistics corridor while the bulk of heavy trucks usage has resulted in severe distress to the pavements. The incessant pouring of heavy lodges on the pavement can aggravate it's weaknesses such as stripping[40]

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Increased Stress Concentration: The use of these vehicles has induced stress that leads to the degradation of the asphalt layer. As an illustration, (Mazar-i-Sharif to Herat Highway) is said to have portions where replacement of the asphaltic surfacing had to be done because of severe stripping suffered due to heavy traffic. This is visible in the form of cracks and raveling of the surface. The reason behind these condition is that the pavement was over stressed with concentrated, determinant and multi directional, static loads[43].
Dynamic Loading Effects: The poorly maintained roads in Afghanistan combined with excessive and aggressive weaving of vehicles further assists in the aggravation of stripping. On (Kandahar-Quetta Highway), high velocity of military and commercial vehicles results in powerful impacts that the motorway structures suffer from, rendering the asphalt film around the aggregates in retentive state severely fractured[44]. Moisture penetrates the bond and further causes degradation[38].
Poor Aggregate Surface Chemistry: It is known that the less compacted aggregates tend to fail under huge loads.[40] Issues of substandard aggregate materials in combination with enormous traffic volumes show the failures of pavements on countryside roads across Ghazni Province. Bonding problems have been associated with an increase in stripping events along the routes that are used for agricultural transport.
Moisture Deterioration: Continual infiltration of moisture in cracks may become a major problem after rains. For example, certain segments of Salang Pass Road tend to experience additional stripping during monsoons, especially with increased traffic. These conditions increase and accelerate the deterioration of the pavement, particularly the bond between the asphalt layers[38].
Exacerbated by Inadequate Design and Maintenance: A large portion of Afghanistan's flexible pavements are of lower standards and do not meet the current traffic expectations. An example of this is the Ring Road, which is a main artery connecting all key cities. It suffers from premature failure due to insufficient design consideration and new traffic requirements [45]. Such failure has also been aggravated because of stripping and erosion due to lack of proper care.

4.Potholes

Road infrastructure is very much affected by potholes -a bowl shaped depression that cuts through the Hot Mix Asphalt (HMA) and goes deep down to the base course [46]. These potholes are chunky and consists of a sharp edge which makes it dangerous for vehicles to move at high speeds [47]. Such conditions are often found on roads which has HMA surface of 25mm to 50 mm and hardly comes across in roads that have 100 mm deep surfaces [48]. Afghanistan is known for using low grade materials for construction of roads making it unable to support stress from heavy traffic load which leads to fatigue cracking [35]. The well-known Kabul-Jalalabad and Kandahar-Herat highways are notorious for their poor condition. You can see in the Fig. 3 a road in Jalalabad that has many potholes and makes it very difficult for vehicles to drive properly. When there is moisture seepage, which especially happens during the rainy season, it erodes the overall health of the pavement. This is because the trapped water gets a chance to freeze which later expands and cracks the pavements even more. Moreover, there is a lack of required maintenance from both local or international institutions for constant better upkeep which worse the problem [18].

Fig. 2. A Road in Jalalabad with potholes.

2.2 Environmental and Climatic Reasons:

Afghanistan's climate and geography have a direct impact on the sustainability and quality of performance of flexible pavements. Temperature, rains, and moisture levels contribute to the myriad types of pavement failure that are observed. These factors create problems that impact the road infrastructural durability and its functionality[7].

In Afghanistan, environmental conditions like temperature, amount of precipitation, and level of moisture are very important for the quality and performance of flexible pavements, but in practice, the construction, repair, and upkeep of local roads is usually centered on the structural depth of the pavement layers, which is set according to the expected volume of traffic.

Temperature: The temperature changes during different seasons greatly influence the condition of underlying asphalt pavements in Afghanistan. For example, some regions of Balkh and Samangan dramatically drop their temperatures during winter, which makes the freeze-thaw cycle very prominent. Road breakages like cracks and brittleness is caused by deked-power asphalt pavements in summer. Moreover, harsh hot weather causes devastating and extreme damage to asphalt. Roads within Balkh and Samangan are prone to deformation and potholing because of differential settlement at the later stages of winter and spring thaw seasons [19].
Precipitation: The precipitation in any form can affect flexible pavements. Especially in spring, these regions, especially Badakhshan and Nuristan, get substantial surface water on their roads which can impair the skid resistance and increase the chance of hydroplaning, and as such, become prone to get damaged easily requiring surface maintenance frequently [49].

Fig. 3. Pavement deterioration in Nuristan from rainfall-induced potholes and erosion.

Moisture: In places like Kandahar and Helmand which contain wide stretches of clay soils, the moisture content is vital in determining the pavement conditions. Following heavy showers, the remnants of the soil is beneath the surface clay and can result in visible swelling and cracking. Low drainage issues can increase these problems in creating a bumpy and dangerous surface for driving on [50,8].

2.3. Effects of Groundwater

The depth of the groundwater table (GWT) in Afghanistan is a crucial factor which contributes in determining the condition of flexible pavements. particularly in low-lying areas like Kunduz Province near the Amu Darya River [51]. causes a lot of subgrade oversaturation which leads to extreme level of pavement distressing like rutting with overstressed flow [20, 52]. Such changes in level of GWT coupled with intricately shifting topography of the region can cause severe degradation of pavement structure in long term [53].

Impact on Pavement Distresses:

Top-Down Cracking: Increases in the water GWT will also reduce the range of top-down crack extension that is predicted at the surface because asphalt overlaps more flexibly with the more moisture saturated lower levels [54].

Nonetheless, the long-term stiffness of the base as well as the subgrade can undermine this effect[55]. For instance, the roads in the section of the Kabul-Kunduz Highway near the Darya -ye-Qonduz may not show many surface cracks on the roads due to moisture [31]. In the long run, the damaged subgrade results in cracking of surface pavements and complete disintegration of the pavement structure[16]

Bottom-Up (Fatigue) Cracking: A high water table compromises the subgrade support, making it susceptible to bottom-up cracking [56]. Increased fatigue cracking at the bottom of the asphalt concrete layer is very common because of higher bending strains [57]. Like other segments of the **part of the Kabul-Jalalabad Highway closest to the Kabul River**, there is extensive fatigue cracking due to the aggressive water table's effect on subgrade saturation [58]. This is worsened by the heavy truck traffic to and from Iran which puts tremendous strain on already weakened pavement structures.

Rutting: There is no direct evidence supporting the water table's bearing on the fissures rutting on the asphalt concrete layer. However, subgrade rutting has heavy dependence on the level of the groundwater table. Silty and clayey soils behave differently [59]. Particularly in Ghazni Province, the soil is largely dominated by silt, and when the GWT is shallow, the loose silt is very prone to rotation especially in spring after freeze, as soils are prone to saturation. This profoundly damages roads, rendering them inadequate for smooth travel or transportation [11].

Subgrade Rutting: The lessened stiffness of the subgrade due to moisture saturation results in greater deformation under traffic loads[60]. Pavement in the Bamiyan Charikar Hwy, which has a high water table combined with high clay content, is subject to severe rutting because the saturated clay turns plastic and flows, which causes large pavement distortions [59, 8].

2.4. Geometric Design Reasons

The geometry design of a roadway covers the dimensions and arrangements of the pavement features. These features encompass channelization [61], intersections, pavement widths, slope, and horizontal and vertical alignment, all of which can impact the safety, capacity, and operation of the roadway network [62]. The Afghan flexible pavements failure can be attributed to several correlations that interrelate with the geometric designs of roadways. If one considers the distinct tumultuous landscapes, socio-economic conditions, and conflicts within Afghanistan [63], one can notice the following prominent issues:

Many predetermined road widths are insufficient: Numerous roads are designed without factoring in the increased volume of heavy vehicle traffic [64]. For instance, the primary highway that links Kabul and Kandahar is frequently oversaturated and too narrow for the high influx of transport vehicles which results in surface wear and increased rutting thresholds due to overly filled conditions [15].

Weak horizontal and vertical alignments: Steep gradients and sharp curves are prevalent within mountainous regions [15, 65]. One of the most important routes, Salang Pass [66], is burdened with inadequate design caliber leading to severe portion of the pavement over curvature stress. Such conditions result in the frequent damages to the road that lead to constant spending of large sums of money for reparations.

Figure. 3. Pavement stress from poor alignment (Salang Pass)

Poor Drainage Facilities: Inadequate drainage contributes to the moisture-induced damage of pavements [67]. For example, roads in Mazar-i-Sharif, a town located in the northern part of the Afghanistan, are prone to water stagnation during the monsoon season, which subsequently leads to structural damage through cracking and other deterioration processes [30].

Lack of Care and Safety: Routine maintenance of the infrastructure is neglected because of war activities and the scant resources available to the government [8]. Roads like the Ring Road that link different provincial capitals remain unrepaired for long periods, allowing minor damages to escalate into significant structural failures [64].

III. REPAIRING OF FLEXIBLE PAVEMENT

Due to the nature of issues existing with flexible pavements in Afghanistan, it is important to incorporate as many efficient and appropriate repair techniques as possible for enhancing asphalt durability and safe use of the roads [15]. This part identifies some of the diverse maintenance techniques that can be utilized in Afghanistan's environmental, traffic, and structural conditions. These strategies can greatly help in reducing the effects of the previously mentioned failures such as ruts, cracks, and sustained potholes, while achieving a self-sufficient road system [68].

Repairing Potholes with Asphalt Concrete (Plant Hot Mix AC)

First mark the area of a pothole rectangularly, then remove the loose bound material until a solid pavement base is encountered beneath. The hole should be filled with M30 aggregate; CSS-1 primer should then be applied (0.8-1.2 L/m²), and finally add hot asphalt mix (AC).) The area may then be compacted with a plate or roller, and will be ready for immediate use as traffic circulation can commence straight away[69].

This method is supplied on primary routes such as the Kabul-Jalalabad highway which suffer from potholes forming as a consequence of intense freeze-thaw cycles throughout winter.

Pothole Repair with Excel Patch (Cold Mix Asphalt)

Pour in Excel Patch cold asphalt mix and set the compaction material to 40% for adequacy. Clean the pothole, and if deeper than 5cm, fill it with coarse material. Spread sand on top, and compact the area using foot, car tires, or a vibrating plate[69].

This is an ideal level of severity peaceful for postponed focus to be used on lower bang city roads during rainy seasons due to hot mix plant unavailability. These reserved methods aid dealing with emergencies that occur within the defined timeframe.

Crack Filling (1 Layer: 12mm Aggregate + CRS-2)

The crack must first be cleaned, CRS-2 tack coat (0.5L/m²) applied, and 12mm aggregate added. The area is then compacted with a vibrating plate for small areas, or hand roller for larger areas[69].

On roads like the Kandahar-Herat highway, we have used this technique to repair thermal cracks as part of our efforts to increase the life of the pavement, even in the face of temperature changes.

Crack Filling (2 Layers: 19mm + 12mm Aggregate + CRS-2)

After cleaning the crack, compress 19mm aggregates applying CRS-2 (0.5L/m²). On the first layer, add 19mm aggregate, compact, and repeat for the second layer using 12mm aggregate with CRS-2 (0.3L/m²) [69].

This updated strategy is necessary at border crossings such as Spin Boldak, which sustain continuous heavy truck traffic.

Fog Seal: In Afghanistan, maintenance of its paved roads can be achieved through fog seal as it entails covering existing narrow cracks with a thin layer of emulsified asphalt which prevents further increases of the cracks, while restoring the surface color of the pavement. In Kabul and Jalalabad, where summer temperatures are high, fog seal helps preserve pavement integrity by restricting moisture infiltration [32]. For instance, the application of fog seals on identifying minor cracking along emissions thermal fluctuations can help prevent further road damage [68].

Slurry Seal: Slurry seal can be used to remedy roads that suffer relatively lower issues like raveling or even narrow cracks as it consists of water, asphalt emulsions, and fine aggregates in a single blend [68].

The technique not only seals the pavement but also adds strength to it while keeping the thickness of the pavement constant. In regions such as Paktia where fine aggregates are readily available, the addition of slurry seal treatments enhances skid resistance, especially before the onset of the rainy season [32].

Chip Seal: The chip seal technique can rehabilitate surfaces with low to moderate traffic that gets a bit rough due to a lot of heavy surface [70]. This procedure consists of spraying an emulsion of asphalt followed by embedded crushed aggregates which makes the surface protrude [68]. Using chip seal applications on busy roads like the Kandahar-Herat Highway can assist aid the severe damage to the surface and simultaneously provide pavement maintenance of great value during heavy traffic load [14].

Microsurfacing: Microsurfacing is helpful in treating the structures with moderate distress, as it is composed of a polymer-modified emulsion [48]. Its ability to address rutting and reflective cracking likewise improves driving safety [68]. Urban roads in Kandahar regularly subjected to wearing by different vehicles will be better with microsurfacing [15]. It will strengthen the pavement structure against future damage [13].

Scrub Seal: The scrub seal method is similar to chip seal but is applied with brooms and is used to effectively treat drastically distressed pavements in a cost-effective manner [68].

This technique is handy against cracks as it fills the wedges and restores the surface. In places where roads step into water resistance, such as villages that are graced with the rain after severely eroded during it, scrub seals can be applied[24].

Cape Seal: Cape seal is an innovative technique that is a merger of chip seals and slurry seals that amalgamates both surface and lower level treatment [71]. This combination is important to regions like Mazar-i-Sharif where the roads are met with heavy weight truck usage as they are built on rough surfaces. Applying a cape seal can help sustain knee transit routes maintenance that exacerbate road quality overall [68].

Coats: Surface and tack coats are crucial preparative steps that need to be undertaken if one is working on surface treatment [9]. They ensure that there is no break between layers and that adhesion to regions with shifts in climatic condition is not hindered [68]. Those tack coats applied before resurfacing on roads connecting provincial captains guarantees maximum tackle against moisture failure [48].

IV. CONCLUSION

This analysis sought the reasons which caused the failure of pavements in Afghanistan while aiming to suggest realistic repair options. The primary scientific outcomes are summarized below:

The Identification of Failure Causes:

- The traffic overloads for example, in the case of the heavy vehicles on the Kabul-Kandahar Highway along with low material standards were found to cause rutting, fatigue cracking, and even potholed.
- Certain environmental aspects on their own for example, freeze-thaw cycles, high temperatures along with lack of proper drainage could worsen moisture damage as well as subgrade saturation.

The Impact of Design Flaws:
- Low road breadths paired with poor geometric road alignment (for example Salang Pass) could increase concentration of stresses resulting to early uncontrolled structural failures.

The Effectiveness of Repair Techniques:
- Some short term measures such as the use of fog seals and pothole patching removed the immediate dangers.
- Other long-term measures microsurfacing and slurry seals made the surface more durable with the Afghan weather.
- Pothole Repair:
  Asphalt Concrete (Plant Hot Mix AC)
  Excel Patch (Cold Mix Asphalt)
- Crack Sealing:
  1-Layer Application: 12mm Aggregate + CRS-2
  2-Layer Application: 19mm + 12mm Aggregate + CRS-2

The Recommendations for Sustainable Maintenance:
- The use of polymer-modified asphalt along with the better drainage gave more climate security.
- A pavement management system which responds to traffic and environmental risk to schedule for prioritized repairs should be executed.

Scientific Contribution:

This document combines field work and international best practices to provide a systematic, evidence-based roadmap for Afghanistan's road infrastructure. Focus for further research should be on the local material testing and cost-benefit evaluation of the suggested alternatives.

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