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**EXTENDING URBAN ROAD PAVEMENT
SERVICE LIFE IN NUKUS
(KARAKALPAKSTAN): CLIMATE- AND
SALINITY-RESPONSIVE DESIGN AND
MAINTENANCE**

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***Abstract:** Urban pavements in Karakalpakstan operate under a coupled stress regime: hot, dry summers; cold-season freezing risk; salt-laden dust and saline soils; and concentrated low-speed heavy loads at intersections and bus corridors. These conditions accelerate rutting, cracking, ravelling and moisture-related damage, and can shorten pavement service life when standard designs are imported without adaptation. This paper develops a climate- and salinity-responsive framework for extending pavement life in Nukus and surrounding districts. The method synthesizes mechanistic-empirical pavement design principles, distress taxonomies and preservation practices, and it translates them into a practical set of design and maintenance packages. Illustrative deterioration trajectories show how intersection loading and environmental exposure can shift performance curves, motivating early preventive actions. The main contribution is a locally grounded checklist and treatment selection logic that aligns materials, drainage and maintenance timing with the Aral Sea region context.*

***Keywords:** Karakalpakstan; Nukus; urban roads; pavement performance; rutting; thermal cracking; saline soils; maintenance; mechanistic-empirical design*

1. Introduction

Urban road systems are long-lived assets, but in harsh climates their life-cycle cost is often dominated by early deterioration and reactive maintenance. In Nukus and other cities in Karakalpakstan, pavements are exposed to strong solar heating in summer, potential freezing conditions in winter and salt-laden dust transport associated with the Southern Aral Sea region. National and regional climate profiles for Uzbekistan indicate rising heat risks and variability that can further stress pavements through thermal gradients and aging [8].

From an engineering perspective, these stressors interact with traffic: slow-moving heavy loads and braking near intersections and stops increase rutting and shear damage, especially under high temperatures. Recent research on rutting mechanisms confirms the coupled impact of high temperature, slow speed and braking on rut depth development [6,7]. In addition, saline soils and shallow, mineralized groundwater in the Southern Aral Sea region can compromise subgrade strength and drainage, increasing moisture sensitivity and stripping risk [9].

The aim of this paper is to present an evidence-based framework for extending the service life of urban pavements in Nukus. The objectives are: (i) identify dominant distress mechanisms under Nukus-relevant climate and salinity conditions; (ii) translate mechanistic-empirical design concepts into practical design packages; and (iii) propose a preservation-oriented maintenance schedule that reduces life-cycle cost. The novelty lies in explicitly incorporating salinity and dust constraints into a pavement-life extension framework that is usually discussed in temperate-climate contexts.

2. Materials and Methods

Conceptual basis. The study uses established pavement engineering sources to define distresses, link them to mechanisms and map them to design and maintenance responses. Distress definitions and measurement language follow the FHWA Long-Term Pavement Performance (LTPP) Distress Identification Manual [1]. Design logic uses mechanistic-empirical concepts which explicitly model traffic and climate effects on damage accumulation [2-4].

Local stressor translation. Three local stressor groups were translated into design requirements: (a) hot-dry summers and high pavement temperatures, which increase rutting susceptibility and binder aging; (b) cold-season thermal contraction and potential freezing, which contribute to cracking and moisture damage; and (c) saline soils and salt-laden dust, which influence drainage, subgrade behavior and surface ravelling. Regional salinity evidence for soils and groundwater in the Southern Aral Sea region supports treating chemical and physical salt impacts as non-negligible boundary conditions [9,10].

Illustrative performance curves. To communicate the maintenance implications, we used simplified deterioration curves (Figure 1) representing three urban scenarios: local streets (light traffic), arterials with concentrated bus loads, and intersection approaches where slow speed and braking are frequent. The curves are illustrative, consistent with the concept that damage accumulation rates differ by loading regime and environment; they are not calibrated to LTPP data for Nukus.

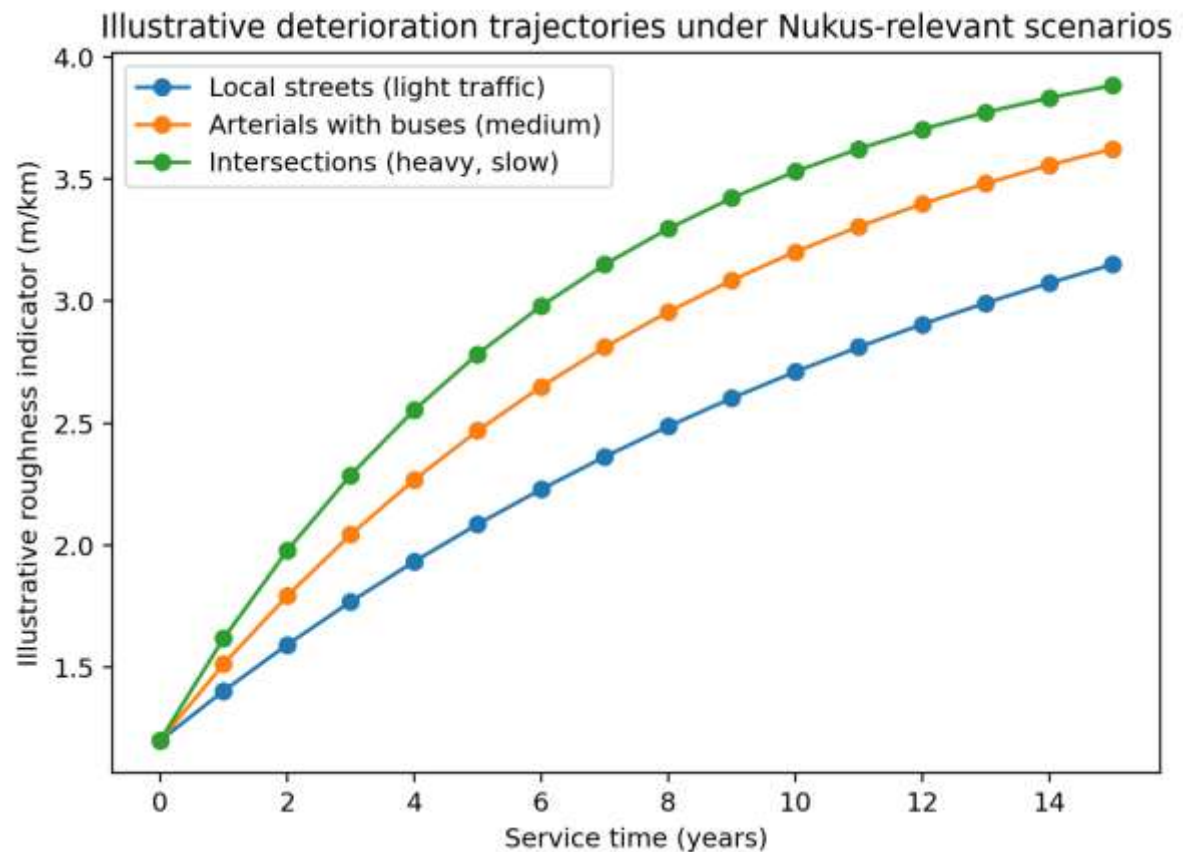


Figure 1. Illustrative deterioration trajectories for three urban loading scenarios relevant to Nukus. Curves are conceptual and used to motivate preservation timing.

Stressor and location	Likely distresses (LTPP language)	Mechanism summary	Design / maintenance response
High pavement temperature on arterials and bus corridors	Rutting; shoving; flushing/bleeding [1]	Viscoplastic deformation and shear under sustained and slow-moving heavy loads; accelerated binder aging [6,7].	Use rut-resistant mix design; consider polymer-modified binder; ensure compaction; manage heavy braking zones with stiffer surface course; early rut filling where needed [2-5].
Cold-season thermal contraction and	Transverse cracking; block cracking [1]	Thermal shrinkage and aging-induced brittleness; higher	Select binder grade to match low-temperature

temperature gradients		cracking risk when temperature swings are large [2-4].	performance; avoid overly stiff aged binders; seal cracks early to prevent moisture ingress [2-5].
Moisture sensitivity and subgrade weakening in saline soils	Ravelling; stripping; edge cracking; pumping [1]	Water and salts reduce adhesion and weaken base/subgrade; poor drainage accelerates damage [9].	Prioritize drainage (shoulders, ditches, outlets); use anti-stripping agents and appropriate aggregate; stabilize subgrade where needed; prevent water entry through sealing and timely patching [2-5,9].
Salt-laden dust and surface abrasion	Surface wear; loss of macrotexture; ravelling [1]	Abrasive particles and salt crystallization can accelerate surface loss, especially where binder ages and becomes brittle [10].	Use durable surface mixes; consider thin overlays or surface treatments on a preservation schedule; improve street cleaning at critical corridors [5,10].

3. Results

The synthesis indicates that the most damaging urban locations in Nukus are likely to be intersection approaches and bus corridors, where heavy loads occur at low speed under high pavement temperatures. Published studies support this mechanism by showing that high temperature combined with slow moving heavy loads and braking markedly increases rutting development [6,7].

Salinity and dust add a second layer of risk: they primarily act through moisture and permeability pathways. When drainage is weak and cracks remain unsealed, salts and water penetrate and accelerate

stripping, base weakening and surface ravelling. Regional evidence of saline soils and groundwater in the Southern Aral Sea region supports treating this as a routine design constraint rather than an exceptional condition [9].

Table 1 provides a practical mapping from stressor to response. Taken together with Figure 1, the results motivate a preservation-oriented strategy: apply preventive surface treatments and crack sealing before the performance curve steepens, especially on corridors with concentrated heavy loading.

Package	Suitable road class in Nukus	Core elements (design and maintenance)
P1: Preservation-first for local streets	Residential/local streets with light traffic	Good drainage and crossfall; crack sealing; periodic surface treatment (fog seal/micro-surfacing where appropriate); timely pothole repair; dust management through cleaning
P2: Rut-resistant arterial package	Arterials with bus routes and freight access	Rutting-resistant asphalt mix; binder selection for high-temperature performance; attention to compaction; anti-stripping; robust base and drainage; schedule for thin overlay before deep rutting
P3: Intersection and stop-zone reinforcement	Intersections, roundabouts, bus stops and approaches	Localized thickening or high-modulus surface layer; reinforcement at braking zones; frequent condition monitoring; rapid rut correction; drainage and joint sealing; targeted rehabilitation triggers

4. Discussion

Implementation in Nukus should prioritize the corridors where deterioration accelerates fastest: high-load, low-speed zones and roads with drainage constraints. Mechanistic-empirical guidance emphasizes that climate and traffic act together to drive damage accumulation, which supports differentiated design rather than a single standard thickness for all streets [2-4].

A second priority is measurement consistency. The LTPP distress manual provides a shared language for identifying rutting, cracking and surface defects and can be used to standardize local condition surveys [1]. With standardized surveys, the city can apply simple decision rules: for example, seal cracks when they are narrow and treat surfaces early, rather than waiting for structural failure.

Limitations. The paper provides a framework and illustrative curves, not a calibrated pavement management system. Local calibration would require traffic counts, axle-load estimates, material properties and climate inputs. Nevertheless, the proposed tables and packages provide a practical starting point for a Nukus-specific pavement standard that explicitly addresses salinity and dust exposure.

5. Conclusion

Urban pavements in Nukus should be designed and maintained for a combined regime of heat, potential freezing, salinity and dust. Using established distress definitions and mechanistic-empirical concepts, this paper mapped local stressors to actionable design and maintenance responses. The results support a preservation-first strategy with differentiated packages for local streets, arterials and intersections, and with strong emphasis on drainage, permeability control and early

preventive maintenance. Building a consistent citywide condition survey using LTPP terminology is recommended as the next step toward a data-driven pavement management system for Karakalpakstan.

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