

MUHANDISLIK

& IQTISODIYOT

ijtimoiy-iqtisodiy, innovatsion texnik,
fan va ta'limga oid ilmiy-amaliy jurnal

№2

2026
fevral



Milliy nashrlar

OAK: <https://oak.uz/pages/4802>

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08.00.00 – Iqtisodiyot fanlar



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РЭУ.РФ
РОССИЙСКИЙ ЭКОНОМИЧЕСКИЙ УНИВЕРСИТЕТ
ИМЕНИ Г.В. ПЛЕХАНОВА
ТАШКЕНТСКИЙ ФИЛИАЛ



muhandislik & iqtisodiyot

ijtimoiy-iqtisodiy, innovatsion texnik,
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*Elektron nashr, 157 sahifa.
2026-yil, fevral*

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Karimova Nilufar Sadirdin qizi, iqtisodiyot fanlari bo'yicha falsafa doktori (PhD)

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- 05.01.00 – Axborot texnologiyalari, boshqaruv va kompyuter grafikasi
- 05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
- 05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
- 05.01.03 – Informatikaning nazariy asoslari
- 05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta'minoti
- 05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
- 05.01.06 – Hisoblash texnikasi va boshqaruv tizimlarining elementlari va qurilmalari
- 05.01.07 – Matematik modellash
- 05.01.11 – Raqamli texnologiyalar va sun'iy intellekt
- 05.02.00 – Mashinasozlik va mashinashunoslik
- 05.02.08 – Yer usti majmualari va uchish apparatlari
- 05.03.02 – Metrologiya va metrologiya ta'minoti
- 05.04.01 – Telekommunikatsiya va kompyuter tizimlari, telekommunikatsiya tarmoqlari va qurilmalari. Axborotlarni taqsimlash
- 05.05.03 – Yorug'lik texnikasi. Maxsus yoritish texnologiyasi
- 05.05.05 – Issiqlik texnikasining nazariy asoslari
- 05.05.06 – Qayta tiklanadigan energiya turlari asosidagi energiya qurilmalari
- 05.06.01 – To'qimachilik va yengil sanoat ishlab chiqarishlari materialshunosligi
- 05.08.03 – Temir yo'l transportini ishlatish
- 05.09.01 – Qurilish konstruksiyalari, bino va inshootlar
- 05.09.04 – Suv ta'minoti. Kanalizatsiya. Suv havzalarini muhofazalovchi qurilish tizimlari
- 10.00.06 – Qiyosiy adabiyotshunoslik, chog'ishtirma tilshunoslik va tarjimashunoslik
- 10.00.04 – Yevropa, Amerika va Avstraliya xalqlari tili va adabiyoti
- 08.00.01 – Iqtisodiyot nazariyasi
- 08.00.02 – Makroiqtisodiyot
- 08.00.03 – Sanoat iqtisodiyoti
- 08.00.04 – Qishloq xo'jaligi iqtisodiyoti
- 08.00.05 – Xizmat ko'rsatish tarmoqlari iqtisodiyoti
- 08.00.06 – Ekonometrika va statistika
- 08.00.07 – Moliya, pul muomalasi va kredit
- 08.00.08 – Buxgalteriya hisobi, iqtisodiy tahlil va audit
- 08.00.09 – Jahon iqtisodiyoti
- 08.00.10 – Demografiya. Mehnat iqtisodiyoti
- 08.00.11 – Marketing
- 08.00.12 – Mintaqaviy iqtisodiyot
- 08.00.13 – Menejment
- 08.00.14 – Iqtisodiyotda axborot tizimlari va texnologiyalari
- 08.00.15 – Tadbirkorlik va kichik biznes iqtisodiyoti
- 08.00.16 – Raqamli iqtisodiyot va xalqaro raqamli integratsiya
- 08.00.17 – Turizm va mehmonxona faoliyati

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Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

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MUNDARIJA

RIVOJLANGAN MAMLAKATLAR BANKLARIDA RISK-MENEJMENTNING TASHKILIY MODELLARI.....	26
Madaminov Bekzod Allayarovich	
“HUDUDGAZTA’MINOT” AJ DA AMALGA OSHIRILGAN LOYIHALAR SAMARASI	32
Shukurillaev Jahongir Botir o’g’li	
HARBIY XIZMATCHI AYOLLARNING MAXSUS KIYIM SIFATIGA QO’YILADIGAN DASTLABKI TALABLARNI SHAKLLANTIRISH	37
Abduraxmanova N.D., Mirtolipova N.X., Nasirullayeva G.S.	
СОВРЕМЕННОЕ СОСТОЯНИЕ ПРОБЛЕМЫ НЕСПЕЦИФИЧЕСКОГО ЯЗВЕННОГО КОЛИТА У ДЕТЕЙ	42
Закирова Бахора Исламовна, Каримов Достон Рустам угли	
ОЦЕНКА ВОЗДЕЙСТВИЯ ФИСКАЛЬНЫХ И КРЕДИТНЫХ ИНСТРУМЕНТОВ НА РЫНКИ ВЫСОКОЛИКВИДНОЙ ПРОДУКЦИИ И ЕСТЕСТВЕННЫХ МОНОПОЛИЙ В РЕСПУБЛИКЕ УЗБЕКИСТАН.....	48
Бекзод Умматов	
ТРАНСФОРМАЦИЯ СИСТЕМ БУХГАЛТЕРСКОГО УЧЕТА В УСЛОВИЯХ ЦИФРОВИЗАЦИИ: СРАВНИТЕЛЬНЫЙ ЭКОНОМИКО-СТАТИСТИЧЕСКИЙ АНАЛИЗ ЭФФЕКТИВНОСТИ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА.....	55
Вахидов Азизжон Саиджонович	
SUG’URTA FAOLIYATIDAGI MOLIVAVIY RISKLAR: BAHOLASH VA MINIMALLASHTIRISH STRATEGIYALARI	58
Xalikulova Shirin Utkir qizi	
“ANDIJONDONMAHSULOT” AJ MISOLIDA XARAJATLARNING STRATEGIK BOSHQARUV HISOBI: AMALIY TAHLIL VA TAKOMILLASHTIRISH TAVSIYALARI	62
Xayitboyeva Laylo Oybekovna	
XORIJIIY MAMLAKATLARNING NORASMIY IQTISODIYOT DARAJASINI PASAYTIRISHDAGI TAJIRIBASI	66
Alimardonov G’ayratjon Nuraliyevich	
XO’JALIK YURITUVCHI SUBYEKTLARDA BARQARORLIK HISOBOTLARI AUDITINI SHAKLLANTIRISH	72
Xolikov Ravshan Anvar o’g’li	
PUL - KREDIT SIYOSATINING TRANSMISSION MEXANIZMINI RIVOJLANTIRISH	76
Obidova Zilola Ikromjon qizi	
HOMILADORLIK DAVRIDA AYOLLARDA UCHRAYDIGAN GESTOZLI KATARAL GINGIVITNI KOMPLEKS DAVOLASHNI OPTIMALLASHTIRISH	81
Nomurodova Farangiz Lazizovna	
AGRAR KORXONALARDA INNOVATSION TEXNOLOGIYALARNI JORIY ETISHDA INVESTITSIYA MEXANIZMLARINING IQTISODIY SAMARADORLIGI VA RIVOJLANTIRISH YO’NALISHLARI	87
Egamberdiyev Abdujabbor Xusanovich	
YOSHLAR TADBIRKORLIGI VA KICHIK BIZNES IQTISODIYOTINI TA’MINLASHDA INFRATUZILMALARDAN FOYDALANISH IMKONIYATLARI	92
Mirzatov Baxtiyor Toxirovich	
KICHIK BIZNES SUBYEKTLARI FAOLIYATINI BAHOLASH METODOLOGIYASINING MAZMUNI VA TAMOIYILLARI	96
Mavrulov Ravshan Nematjonovich	



УПРАВЛЕНИЕ ИНФОРМАЦИОННЫМИ КОММУНИКАЦИЯМИ В ПРОЕКТАХ	101
Носирова Гулираъно Абдулазиз кизи	
DAVLAT BUDJETI JARAYONIDA MONITORING VA MOLIVAVIY NAZORATNI TAKOMILLASHTIRISH MASALALARI	107
Yax'yayeva Dilfuza Bagdatovna	
XIZMAT KO'RSATISH SOHASIDA KICHIK KORXONALAR RAQOBATBARDOSHLIGINI OSHIRISH MEKANIZMLARINI TAKOMILLASHTIRISH	111
Axmedov Sanjar Temur o'g'li	
RAQAMLI MOLIYA TEXNOLOGIYALARI EVOLYUTSIYASINING ISTIQBOLLI YO'NALISHLARI VA YUZAGA KELISHI MUMKIN BO'LGAN XATARLAR TAHLILI	117
Ko'chimov Jahongir Shuxrat o'g'li	
GAZ VA GAZ KONDENSATINI YIG'ISH VA TAYYORLASH TIZIMLARI UCHUN ZAMONAVIY LOYIHALASH USULLARI TAHLILI	123
Abdirazakov Akmal Ibragimovich6 Namozov Og'abek Maxmud o'g'li	
AGILE PROJECT MANAGEMENT IN THE DIGITAL ERA: STRATEGIES, FRAMEWORKS, AND BEST PRACTICES FOR SUCCESS	128
Utkirova Maftuna Murodjon qizi	
O'ZBEKISTON EKSPORTYOR KORXONALARINING YANGI BOZORLARGA CHIQISHIDA FAOL MARKETING VOSITALARIDAN FOYDALANISH HOLATI VA MUAMMOLARI	134
Baqoyev Sunnatillo Burxon o'g'li	
TADBIRKORLIK FAOLIYATIGA RAQAMLI TEXNOLOGIYALARNI JORIY ETISHNING ILMIY-NAZARIY ASOSLARI	139
Salaydinov Shodiyor Nizom o'g'li	
TO'QIMACHILIK SANOATIDA INVESTITSION LOYIHALARNI BOSHQARISH METODOLOGIYASINI TAKOMILLASHTIRISHNING TASHKILIY-IQTISODIY JIHATLARI	144
Qurbonov Jasurbek Pozilovich	
OPTIMIZATION OF ROADSIDE AUTO CAMPING SITES (REST AREAS) ON HIGHWAYS USING ARTIFICIAL INTELLIGENCE: INFRASTRUCTURE GAPS AND CORRIDOR-BASED EVIDENCE FROM UZBEKISTAN	150
Akramov Akbarjon Akmal ugli	



OPTIMIZATION OF ROADSIDE AUTO CAMPING SITES (REST AREAS) ON HIGHWAYS USING ARTIFICIAL INTELLIGENCE: INFRASTRUCTURE GAPS AND CORRIDOR-BASED EVIDENCE FROM UZBEKISTAN

Akramov Akbarjon Akmal ugli

Doctoral (PhD) Student (Basic Doctorate)

Specialization: Service Sector Economics

Research Institute for Tourism Development under the Tourism Committee of the Republic of Uzbekistan

E-mail: akbarshah97uz@gmail.com

Abstract. The road network plays a decisive role in Uzbekistan's transport system due to the country's double-landlocked position and its reliance on long-distance overland corridors for domestic and international connectivity. In recent years, large-scale modernization initiatives have been implemented to rehabilitate strategic highways, strengthen international corridors, and improve overall transport efficiency. At the same time, challenges persist regarding infrastructure quality, safety performance, and the provision of roadside services. This article examines the current condition of Uzbekistan's highway system, analyzes key structural and safety-related issues, and places particular emphasis on the state of roadside rest areas as an integral yet still insufficiently developed component of road infrastructure. Drawing on academic studies and official documentation from international development institutions, the study shows that, while corridor rehabilitation increasingly follows a system-based approach, standardized and accessible roadside service facilities remain unevenly developed. The results indicate that improving the coverage and quality of rest areas should be regarded as a necessary element of road safety and corridor performance rather than as a supplementary service.

Keywords: Uzbekistan; highways; road infrastructure; transport corridors; road safety; roadside auto camping sites; roadside rest areas; infrastructure optimization; artificial intelligence; transport modernization.

Annotatsiya. Avtomobil yo'llari tarmog'i O'zbekiston transport tizimida hal qiluvchi ahamiyatga ega bo'lib, bu holat mamlakatning ikki tomonlama quruqlik bilan o'ralgan geografik joylashuvi hamda ichki va xalqaro bog'liqlikni ta'minlashda uzoq masofali quruqlik transport koridorlariga bo'lgan yuqori darajadagi tayanishi bilan izohlanadi. So'nggi yillarda strategik avtomobil yo'llarini rekonstruksiya qilish, xalqaro transport koridorlarini mustahkamlash va umumiy transport samaradorligini oshirishga qaratilgan keng ko'lamli modernizatsiya tashabbuslari amalga oshirildi. Shu bilan birga, infratuzilma sifati, yo'l harakati xavfsizligi ko'rsatkichlari va yo'lbo'yi xizmatlar bilan ta'minlash darajasiga oid masalalar dolzarbligicha qolmoqda. Mazkur maqolada O'zbekiston avtomobil yo'llari tizimining hozirgi holati ko'rib chiqilib, asosiy strukturaviy va xavfsizlik bilan bog'liq masalalar tahlil qilinadi hamda yo'l infratuzilmasining ajralmas, biroq hozircha yetarli darajada rivojlanmagan elementi hisoblangan yo'lbo'yi dam olish maskanlarining holatiga alohida e'tibor qaratiladi. Ilmiy tadqiqotlar va xalqaro rivojlanish institutlarining rasmiy hujjatlariga tayangan holda o'tkazilgan tahlil natijalari shuni ko'rsatadiki, transport koridorlarini rekonstruksiya qilishda tizimli yondashuv tobora keng qo'llanilayotgan bo'lsa-da, standartlashtirilgan va foydalanish uchun qulay yo'lbo'yi xizmat obyektlari hana notekis rivojlangan. Tadqiqot natijalari dam olish maskanlari qamrovi va sifatini oshirishni yo'l harakati xavfsizligi hamda transport koridorlari samaradorligining zaruriy elementi sifatida ko'rish lozimligini, ularni faqat yordamchi xizmat sifatida baholash yetarli emasligini ko'rsatadi.

Kalit so'zlar: O'zbekiston; avtomobil yo'llari; yo'l infratuzilmasi; transport koridorlari; yo'l harakati xavfsizligi; avto kempinglar; yo'lbo'yi dam olish maskanlari; infratuzilmani optimallashtirish; sun'iy intellekt; transportni modernizatsiya qilish.



Аннотация. Дорожная сеть играет ключевую роль в транспортной системе Узбекистана в силу двойного внутриконтинентального географического положения страны и её зависимости от протяжённых наземных транспортных коридоров для обеспечения внутренней и международной связанности. В последние годы реализованы масштабные инициативы по модернизации, направленные на реконструкцию стратегических автомагистралей, укрепление международных коридоров и повышение общей эффективности транспортной системы. Вместе с тем сохраняются вызовы, связанные с качеством инфраструктуры, показателями дорожной безопасности и уровнем развития придорожных сервисов. В статье рассматривается текущее состояние автомобильных дорог Узбекистана, анализируются ключевые структурные и связанные с безопасностью вопросы, а также уделяется особое внимание состоянию придорожных зон отдыха как неотъемлемого, но пока недостаточно развитого элемента дорожной инфраструктуры. На основе анализа научных исследований и официальной документации международных институтов развития показано, что, несмотря на всё более широкое внедрение системного подхода в рамках коридорной реконструкции, стандартизированные и доступные придорожные сервисные объекты развиты неравномерно. Полученные результаты свидетельствуют о том, что расширение охвата и повышение качества зон отдыха следует рассматривать как необходимый элемент дорожной безопасности и эффективности транспортных коридоров, а не как вспомогательную услугу.

Ключевые слова: Узбекистан; автомобильные дороги; дорожная инфраструктура; транспортные коридоры; дорожная безопасность; придорожные автокемпинги; зоны отдыха; оптимизация инфраструктуры; искусственный интеллект; модернизация транспорта.

INTRODUCTION

Road transport constitutes the dominant mode of movement for passengers and freight in Uzbekistan and represents a critical factor in the country's economic competitiveness. Owing to its double-landlocked geographical position, Uzbekistan depends heavily on efficient domestic and international road corridors to ensure access to regional markets and global supply chains [1,2]. The importance of road infrastructure is further underscored by the role of the transport sector in the national economy, which accounts for approximately 8% of GDP, 17.6% of fixed assets, and nearly 30% of paid services to the population, with road transport alone contributing more than 3% of GDP [1]. Transport and logistics costs therefore exert a substantial influence on trade performance, investment attractiveness, and regional development outcomes [1,2,9].

Academic and policy-oriented studies on Uzbekistan's transport sector emphasize that the effectiveness of the road network cannot be assessed solely by its physical length. Increasing attention is being directed toward infrastructure quality, corridor continuity, safety performance, and the availability of supporting services [1,2]. Following a prolonged period of underinvestment after the post-Soviet transition, the road sector has entered a phase of active modernization, with particular emphasis on international transport corridors and interregional routes [2]. Despite these efforts, structural challenges persist, including uneven maintenance standards, safety risks on long-distance highways, and the still limited development of roadside service infrastructure [5].

Within this context, roadside rest areas represent a specific yet frequently underestimated component of road infrastructure. International practice increasingly recognizes rest areas as integral elements of road safety systems, freight efficiency, and user comfort, particularly along long-distance corridors with high traffic intensity [10]. In Uzbekistan, however, systematic analysis of roadside rest areas and their role within the highway system remains limited, and existing studies tend to address road rehabilitation and safety issues without explicitly examining roadside service provision as a distinct infrastructure element.

This research gap is especially relevant in light of the growing emphasis on corridor-based transport development and safety-oriented road management. The absence of standardized, accessible, and predictably distributed rest areas may reduce the overall effectiveness of corridor modernization efforts and increase fatigue-related safety risks on long highways [5].

Accordingly, the aim of this article is to provide an integrated assessment of Uzbekistan's highway system with particular emphasis on the condition and role of roadside rest areas. The study seeks to identify structural and safety-related challenges associated with roadside service provision and to evaluate their relevance within broader corridor modernization initiatives. By synthesizing academic research and official documentation from international development institutions, the article contributes to the transport infrastructure literature by highlighting roadside rest areas as a functional component of road safety and corridor performance rather than as a supplementary service.

The remainder of the paper is structured as follows. Section 2 outlines the materials and research methods employed. Section 3 presents the main results concerning the characteristics of the road network, corridor modernization efforts, road safety conditions, and the current state of roadside rest areas. Section 4 discusses

the implications of the findings in relation to international practices and future infrastructure optimization, while Section 5 concludes the study and outlines directions for further research.

LITERATURE REVIEW

The academic literature on Uzbekistan's transport sector emphasizes the strategic importance of road infrastructure for national economic development and regional integration. Due to the country's double-landlocked position, efficient road corridors are widely recognized as essential for ensuring access to regional markets and global supply chains [1,2]. Studies focusing on transport and logistics systems indicate that transport costs significantly influence trade performance, investment attractiveness, and regional development outcomes, thereby underscoring the macroeconomic relevance of road infrastructure quality rather than network length alone [1,2,9].

A growing body of research argues that the effectiveness of a road network should be assessed from a system-based perspective that incorporates infrastructure quality, corridor continuity, safety performance, and supporting services [1,2]. Strategic analyses of Uzbekistan's transport development priorities emphasize the modernization of international corridors and interregional routes as a response to prolonged underinvestment following the post-Soviet transition period [2]. At the same time, these studies acknowledge persistent structural constraints, including uneven maintenance standards and safety challenges along long-distance highways [5].

International institutional literature further reinforces the importance of adopting a corridor-oriented approach to road infrastructure development. Reports by international development organizations emphasize that modern highway systems increasingly integrate pavement rehabilitation with measures aimed at improving operational efficiency, safety frameworks, and service infrastructure [3,4]. Within this framework, roadside facilities are viewed as components that enhance corridor reliability and user support rather than as auxiliary amenities.

Road safety constitutes a central theme in both academic and institutional analyses. Global and regional studies underline that accident reduction requires comprehensive interventions extending beyond vehicle standards and enforcement to include infrastructure design and user-oriented facilities [5,6,7]. In the Uzbek context, safety assessments identify speed violations, driver fatigue, and long-distance driving conditions as recurring risk factors, particularly on corridors connecting major urban centers and border crossings [5,7,8]. These findings support the view that infrastructure elements enabling rest and recovery contribute to the mitigation of fatigue-related risks.

Despite the increasing recognition of system-based road management, the literature specifically addressing roadside rest areas in Uzbekistan remains limited. International practice, as reflected in technical guidance and safety frameworks, increasingly treats rest areas as integral elements of road safety systems, freight efficiency, and user comfort, especially on high-traffic and long-distance corridors [10]. However, existing national-level studies and policy documents tend to address roadside services indirectly or as secondary components within broader infrastructure projects, rather than as independent subjects of analysis [3,5].

Recent corridor rehabilitation initiatives supported by international development institutions indicate a gradual shift in this approach by explicitly incorporating rest and service areas into project design [3,4]. These initiatives emphasize requirements related to safety, sanitation, accessibility, and inclusivity, suggesting increasing alignment with evolving international standards [10]. Nevertheless, the uneven development and limited documentation of existing roadside facilities point to a clear research gap regarding their current condition, functional role, and integration within Uzbekistan's highway system.

RESEARCH METHODOLOGY

This study employs a qualitative and descriptive research design based on the analysis of academic literature and official documentation related to Uzbekistan's road and transport sector. This methodological approach is well suited to examining the structural characteristics, policy orientations, and institutional practices associated with highway infrastructure and roadside service provision.

The core academic foundation of the analysis consists of national and regional studies addressing transport strategy, logistics development, and road infrastructure performance in Uzbekistan. These sources provide insight into network characteristics, policy priorities, safety considerations, and long-term development objectives [1–6]. The reviewed literature is used to contextualize the current state of the highway system and to identify recurring structural and safety-related challenges.

To ensure institutional reliability and analytical consistency, the study also draws on publicly available documentation from international organizations actively engaged in Uzbekistan's road sector, including international development banks and United Nations agencies [3–7,9]. These materials are used to examine



corridor modernization initiatives, safety indicators, and the extent to which roadside services are incorporated into contemporary infrastructure programs.

The analytical procedure follows a three-stage structure. First, the general condition and structural characteristics of Uzbekistan's road network are summarized based on academic and institutional sources. Second, recent trends in corridor modernization and road safety performance are examined with reference to documented project frameworks and safety assessments. Third, the condition of roadside rest areas is assessed through the lens of existing policy documents, project requirements, and international safety frameworks, thereby enabling the identification of structural gaps without resorting to speculative assumptions.

The study does not rely on primary data collection or statistical modeling. Instead, it adopts an interpretative approach that synthesizes qualitative evidence from verified secondary sources. This method allows for a system-based assessment of roadside rest areas as part of the broader highway infrastructure, while maintaining analytical transparency and consistency with the objectives of the study.

ANALYSIS AND RESULTS

General Characteristics of the Road Network

Uzbekistan's road network extends to approximately 184,000 kilometers, including more than 42,000 kilometers of public roads with a hard surface [13]. This network constitutes the backbone of domestic mobility and regional connectivity, linking major urban centers, industrial zones, and international border crossings. Strategic transport literature identifies the road system as a key component of Uzbekistan's connections with neighboring states and international trade corridors [2].

National transport development strategies prioritize the strengthening of routes within international transport corridors, the enhancement of load-bearing capacity on major highways, and the gradual improvement of local road networks to support regional social and economic development [2,9]. Comparative indicators show that Uzbekistan's integrated transport network density index is 1.63, exceeding that of some regional peers, such as Kazakhstan and Russia, while remaining lower than that of developed economies, including France and Germany [12].

Corridor Modernization and Institutional Support

Recent years have been characterized by corridor-oriented modernization initiatives supported by international development institutions. Rehabilitation projects along strategic highways increasingly combine pavement renewal with operational and safety-related components. For example, the Asian Infrastructure Investment Bank finances the Bukhara Road Network Improvement Project, which focuses on the rehabilitation and maintenance of a 78-kilometer section of the international A380 highway [4].

According to reports by the Asian Development Bank, corridor upgrade projects increasingly incorporate intelligent transport systems, axle-load control mechanisms, and the development of designated rest and service areas [3]. These components are integrated into broader project frameworks aimed at improving highway performance and operational efficiency along international corridors.

Road Safety Indicators

Road traffic safety remains a major public concern in Uzbekistan. According to World Health Organization data, the road traffic mortality rate in the country was approximately 9.3 deaths per 100,000 population in 2021 [7]. Official statistics indicate that 3,559 road traffic accidents were recorded in the first half of 2022, resulting in 784 fatalities and 2,775 injuries [11].

Accident data show that speed-limit violations accounted for 22.9% of recorded accidents, while failure to maintain a safe distance and driver inexperience together accounted for more than 12% [11]. These factors are frequently observed under long-distance driving conditions. Additional safety assessments note the presence of seasonal congestion and mixed traffic composition on major highways, which further underscores the importance of comprehensive safety-oriented infrastructure measures [5].

Condition of Roadside Rest Areas

Available documentation indicates that roadside rest areas in Uzbekistan are unevenly developed across the highway network [3,5]. While informal stopping points, fuel stations, and roadside cafés exist along selected routes, their spatial distribution, service quality, and safety features vary considerably. At present, comprehensive and publicly accessible national inventories of roadside rest areas are not available [5].

Logistics-related assessments further reflect infrastructure constraints. In 2023, Uzbekistan's trade and transport infrastructure quality received a score of 2.40 in the Logistics Performance Index sub-components, representing the lowest score among the evaluated dimensions [14]. This indicator points to limitations in supporting infrastructure along transport corridors.

At the same time, recent corridor rehabilitation projects supported by international institutions explicitly include the construction of new rest and service areas with defined technical and service standards [3]. Project

documentation specifies requirements related to sanitation, lighting, security considerations, accessibility, and the inclusion of electric vehicle charging infrastructure, indicating a gradual alignment with contemporary international practices [9,10].

The results confirm that Uzbekistan's highway system is undergoing a gradual transition from fragmented maintenance practices toward a more integrated, corridor-based modernization approach. Internationally supported rehabilitation projects increasingly combine pavement renewal with measures aimed at improving operational efficiency and safety performance [3,4]. This shift reflects a broader understanding of highways as complex transport systems rather than merely as physical assets, which is consistent with international road safety and corridor management frameworks [5].

Within this system-oriented perspective, roadside rest areas emerge as a functional yet still insufficiently developed element of highway infrastructure in Uzbekistan. Although recent projects explicitly include rest and service areas with defined standards [3], the overall findings indicate an uneven spatial distribution, limited standardization, and the absence of comprehensive national documentation of existing facilities [5]. These characteristics suggest that roadside services have historically been treated as secondary infrastructure components rather than as integral elements of road safety and corridor performance.

The road safety indicators presented in the Results section further underscore the importance of roadside rest areas. Accident statistics show that speed violations, failure to maintain a safe distance, and driver inexperience account for a substantial share of road traffic accidents [11]. International safety literature emphasizes that fatigue and prolonged driving conditions are closely associated with such risk factors, particularly on long-distance corridors [5,7]. In this context, the limited availability of predictable and well-designed rest areas may increase fatigue-related risks, especially in sparsely populated regions where alternative stopping opportunities are limited.

The findings also point to an institutional shift toward the inclusion of safety, accessibility, and inclusivity considerations in newly planned roadside facilities. Project documentation increasingly refers to sanitation standards, lighting, security measures, accessibility features, and gender-responsive design elements [3,10]. The growing prominence of these requirements suggests alignment with evolving international practices, while also indicating that existing roadside infrastructure does not yet consistently meet contemporary safety and inclusivity standards.

From a planning and management perspective, the uneven development and limited documentation of roadside rest areas pose challenges for systematic infrastructure optimization. The absence of reliable inventories, standardized indicators, and usage data constrains evidence-based decision-making and long-term service planning [8]. This limitation is particularly relevant in the context of emerging data-driven approaches to infrastructure management.

In this regard, artificial intelligence-based optimization can be conceptually positioned as a forward-looking tool for improving the planning and operation of roadside auto camping sites and rest areas on highways. Within a system-based framework, AI-driven methods may support the analysis of traffic flows, corridor characteristics, safety indicators, and service demand patterns to inform optimal rest-area placement, spacing, and service composition. Although the present study does not implement algorithmic modeling, the identified structural gaps highlight the potential relevance of such approaches within future transport infrastructure modernization strategies.

Overall, the discussion indicates that improving the coverage and quality of roadside rest areas should be viewed as a core component of highway system performance, closely linked to safety outcomes and corridor efficiency. Integrating roadside services into corridor-based planning frameworks, supported by data-driven and artificial intelligence-assisted decision tools, is consistent with international trends in transport system management and addresses the documented infrastructure gaps within Uzbekistan's road network.

CONCLUSIONS AND RECOMMENDATIONS

This study examined the current state of Uzbekistan's highway system with particular attention to roadside rest areas as an integral yet still underdeveloped component of road infrastructure. The analysis confirms that road transport plays a decisive role in national mobility, economic competitiveness, and regional connectivity, especially in light of Uzbekistan's double-landlocked geographical position and its reliance on long-distance transport corridors.

The findings indicate that recent modernization efforts increasingly adopt a corridor-based and system-oriented approach, supported by international development institutions. These initiatives combine physical rehabilitation with safety and operational components and, in several cases, explicitly incorporate roadside rest and service areas. At the same time, the results show that roadside rest areas remain unevenly distributed, insufficiently standardized, and weakly documented at the national level, which limits their functional contribution to road safety, user comfort, and corridor efficiency.



Road safety indicators further underscore the relevance of roadside services within the broader transport system. Accident statistics associated with long-distance driving conditions highlight the importance of predictable and safe stopping opportunities along major corridors. In this context, roadside rest areas should be regarded not as supplementary amenities but as safety-relevant infrastructure elements that support fatigue management and reliable corridor operation.

From a development perspective, the absence of comprehensive inventories and standardized planning frameworks constrains evidence-based decision-making in roadside service provision. This limitation points to the need for more systematic approaches to rest-area planning and management. Within this framework, artificial intelligence-based optimization represents a promising direction for future infrastructure development. Data-driven methods can support the identification of optimal rest-area locations, service composition, and spacing along highways by integrating traffic patterns, safety indicators, and corridor characteristics.

In conclusion, strengthening the coverage, quality, and integration of roadside auto camping sites and rest areas should be considered a core component of highway modernization policy in Uzbekistan. Future research and planning efforts would benefit from systematic data collection and the gradual incorporation of artificial intelligence-assisted tools to enhance corridor performance, road safety, and user-oriented service provision.

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muhandislik **& iqtisodiyot**

ijtimoiy-iqtisodiy, innovatsion texnik,
fan va ta'limga oid ilmiy-amaliy jurnal

Ingliz tili muharriri: Feruz Hakimov

Musahhih: Zokir Alibekov

Sahifalovchi va dizayner: Abdurahmon Qurbonov

2026. № 2

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"Muhandislik va iqtisodiyot" jurnali 26.06.2023-yildan
O'zbekiston Respublikasi Prezidenti Adminstratsiyasi huzuridagi
Axborot va ommaviy kommunikatsiyalar agentligi tomonidan
№S-5669245 reyestr raqami tartibi bo'yicha ro'yxatdan o'tkazilgan.
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