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INTERNATIONAL EXPERIENCE IN ROAD SECTOR FINANCING AND ROAD ASSET MANAGEMENT: IMPLICATIONS FOR SUSTAINABLE INFRASTRUCTURE DEVELOPMENT IN UZBEKISTAN

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Abstract. Road infrastructure plays a fundamental role in promoting sustainable economic growth, improving transport connectivity, and enhancing regional competitiveness. The long-term performance of road networks largely depends on the effectiveness of financing mechanisms and asset management systems. This study examines international experience in road sector financing and road asset management, with particular emphasis on practices implemented in the United States, Germany, Japan, Australia, and the United Kingdom. The research analyzes major financing mechanisms, including government budget allocations, Road Funds, Public–Private Partnerships (PPPs), toll roads, and financing provided by international financial institutions. In addition, it examines contemporary road asset management approaches based on Life Cycle Cost Analysis (LCCA), the ISO 55000 Asset Management Standards, Geographic Information Systems (GIS), Building Information Modeling (BIM), the Internet of Things (IoT), Digital Twin technology, and Artificial Intelligence (AI). The study also reviews institutional reforms undertaken in Uzbekistan to strengthen road infrastructure governance and financing. Comparative analysis indicates that developed countries increasingly prioritize preventive maintenance, lifecycle asset management, and digital technologies rather than relying primarily on the expansion of road networks through new construction. The findings suggest that Uzbekistan has made significant progress in strengthening institutional capacity and increasing public investment in road infrastructure. However, further reforms are needed to diversify financing sources, implement comprehensive asset management systems, and accelerate digital transformation. The study offers practical policy recommendations aimed at improving the efficiency, sustainability, and resilience of road infrastructure management in line with international best practices.

Keywords: road infrastructure; road asset management; infrastructure financing; Road Fund; Public–Private Partnership; toll roads; ISO 55000; Life Cycle Cost Analysis; Digital Twin; Artificial Intelligence.

INTRODUCTION

Road infrastructure represents one of the most strategic components of a country's economic system. Efficient road networks facilitate domestic and international trade, reduce transportation costs, improve labor mobility, strengthen regional integration, and enhance national competitiveness. Consequently, the quality of road infrastructure has become one of the principal determinants of sustainable economic development in both developed and developing economies.

International experience demonstrates that the sustainability of road infrastructure depends not only on the construction of new roads but also on the availability of stable financing mechanisms and effective road asset management systems. Traditional infrastructure policies primarily emphasized the expansion of road networks through large-scale investments. However, increasing fiscal constraints and the aging of infrastructure have shifted policy priorities toward preserving existing assets and maximizing their lifecycle value.

Over the last two decades, the concept of Road Asset Management (RAM) has become a central element of transport infrastructure policy worldwide. Under this approach, roads are treated as long-term public assets that require continuous monitoring, preventive maintenance, and evidence-based investment decisions

throughout their service lives. Modern asset management integrates engineering, economics, finance, and digital technologies to optimize infrastructure performance while minimizing lifecycle costs.

Developed countries have introduced innovative financing instruments to ensure the long-term sustainability of road infrastructure. These mechanisms include dedicated Road Funds financed through user charges, Public–Private Partnerships (PPPs), toll road concessions, infrastructure bonds, and financing provided by international financial institutions. At the same time, digital technologies such as Geographic Information Systems (GIS), Building Information Modeling (BIM), the Internet of Things (IoT), Digital Twin technology, and Artificial Intelligence (AI) have significantly improved infrastructure monitoring and maintenance planning.

Uzbekistan has also initiated comprehensive institutional reforms aimed at modernizing the road sector. The establishment of centralized governance structures, improvements in procurement mechanisms, increased public investment, and the implementation of national road development programs have created favorable conditions for enhancing road infrastructure management. At the same time, further opportunities remain to strengthen sustainable financing, expand lifecycle asset management practices, accelerate digitalization, and diversify investment sources.

Against this background, examining international best practices provides valuable insights for further improving road infrastructure policies in Uzbekistan.

The objective of this study is to analyze international experience in road sector financing and road asset management and to identify policy recommendations that can support the sustainable development of road infrastructure in Uzbekistan. Specifically, the study compares financing models applied in developed countries, evaluates modern road asset management practices, assesses recent institutional reforms in Uzbekistan, and proposes practical recommendations based on international experience.

LITERATURE REVIEW

Road infrastructure financing and road asset management have become increasingly important research areas in transport economics, public finance, and infrastructure policy. Growing maintenance needs, limited public budgets, climate-related challenges, and rapid technological development have encouraged governments to adopt more sustainable approaches to infrastructure management. Contemporary studies emphasize that effective road asset management requires not only adequate financial resources but also strategic planning based on lifecycle cost optimization, institutional efficiency, and digital technologies.

One of the most influential contributions to road infrastructure financing was made by Heggie and Vickers (1998), who argued that road networks should be managed according to commercial management principles rather than traditional public administration. They emphasized that sustainable financing systems should be based on the “user pays” principle through dedicated Road Funds financed by fuel taxes, vehicle registration fees, and road user charges. Such financing mechanisms reduce dependence on annual government budget allocations while ensuring predictable funding for road maintenance.

Levinson (2012) further expanded this perspective by describing transport infrastructure as a productive public asset rather than merely a public expenditure. According to his analysis, investments in road infrastructure generate long-term economic benefits by improving accessibility, reducing logistics costs, increasing labor mobility, and enhancing regional competitiveness. Consequently, road infrastructure investments should be evaluated from both engineering and macroeconomic perspectives.

Modern research increasingly focuses on Road Asset Management (RAM), which treats highways and road networks as strategic national assets requiring continuous performance monitoring throughout their lifecycle. Haas, Hudson, and Zaniewski (1994) introduced pavement management systems that integrate engineering assessment with economic analysis to determine the optimal timing of maintenance and rehabilitation activities. Their findings demonstrate that preventive maintenance performed at appropriate intervals substantially reduces long-term rehabilitation costs while extending pavement service life.

The concept of Life Cycle Cost Analysis (LCCA) has become one of the fundamental analytical tools in road asset management. Rather than minimizing initial construction costs, LCCA evaluates all expenditures associated with planning, construction, maintenance, rehabilitation, operation, and disposal throughout an asset’s service life. Numerous international studies conclude that lifecycle-oriented investment decisions significantly improve infrastructure sustainability and reduce overall public expenditure.

International organizations have also contributed significantly to the development of road asset management frameworks. The World Bank has consistently promoted institutional reforms that combine sustainable financing mechanisms with transparent governance and performance-based maintenance systems. Similarly, the Asian Development Bank (ADB) and the Organisation for Economic Co-operation and Development (OECD) recommend integrating infrastructure investment planning with long-term asset management strategies to maximize economic returns.

The publication of the ISO 55000 Asset Management Standards represented a major milestone in infrastructure management. ISO 55000 provides internationally recognized principles for managing physical assets throughout their lifecycle, emphasizing risk management, value creation, stakeholder engagement, and continuous organizational improvement. Many developed countries have incorporated the principles of ISO 55000 into their national road management systems to improve investment efficiency and infrastructure resilience.

Digital transformation has further reshaped road asset management practices. Geographic Information Systems (GIS) enable the spatial monitoring of road conditions, while Building Information Modeling (BIM) supports integrated infrastructure planning and construction management. Internet of Things (IoT) sensors provide real-time monitoring of pavement conditions, bridge performance, traffic loads, and environmental impacts. More recently, Digital Twin technology has enabled infrastructure agencies to create virtual replicas of physical assets, facilitating predictive maintenance and scenario analysis. Artificial Intelligence (AI) has also become increasingly important in automating pavement condition assessment, forecasting deterioration rates, optimizing maintenance schedules, and improving investment prioritization.

International experience demonstrates considerable variation in financing models. The United States relies on federal and state Highway Trust Funds financed primarily through fuel taxes and user charges. Germany combines federal budget financing with toll-based systems for heavy vehicles. Japan extensively utilizes toll expressways managed through public corporations and concession arrangements. Australia applies performance-based asset management supported by comprehensive pavement management systems, while the United Kingdom increasingly emphasizes lifecycle planning and digital infrastructure management under the ISO 55000 framework.

Recent institutional reforms in Uzbekistan indicate a gradual transition toward internationally recognized approaches. Government initiatives have strengthened centralized road governance, introduced competitive procurement procedures, expanded investment in road maintenance, and improved institutional coordination. At the same time, additional opportunities remain to further develop sustainable financing mechanisms, implement integrated road asset management systems, expand the application of digital infrastructure technologies, and strengthen evidence-based investment planning in line with international best practices.

Despite the growing body of international literature, relatively few studies comprehensively analyze the relationship between infrastructure financing mechanisms and road asset management within the context of developing economies, particularly in Central Asia. Most previous research focuses either on financing models or on the engineering aspects of asset management separately. This study seeks to bridge this gap by integrating both dimensions and evaluating how international experience can support the modernization of Uzbekistan's road infrastructure management system.

RESEARCH METHODOLOGY

Research Design

This study employs a qualitative comparative research design to investigate international practices in road sector financing and road asset management. The research integrates institutional, financial, and technological perspectives to evaluate how different countries organize sustainable road infrastructure financing and manage road assets throughout their lifecycles. The comparative approach enables the identification of policy instruments and management practices that may be adapted to the institutional context of Uzbekistan.

Data Sources

The analysis is based on both primary and secondary sources of information. Primary documentary sources include official legislative and policy documents of the Republic of Uzbekistan concerning road sector reforms, infrastructure financing, and institutional development. Government budget reports related to road infrastructure expenditure for the period **2022–2025** also constitute an important empirical basis for the analysis.

Secondary data were obtained from internationally recognized publications issued by the World Bank, the Asian Development Bank (ADB), the Organisation for Economic Co-operation and Development (OECD), the International Monetary Fund (IMF), PIARC (World Road Association), and ISO standards. Academic literature addressing transport economics, infrastructure finance, pavement management, lifecycle asset management, and Public–Private Partnership (PPP) models was also extensively reviewed.

The combination of national policy documents and international literature provides a comprehensive basis for evaluating current practices and identifying opportunities for policy improvement.

Research Methods

Several complementary research methods were employed to achieve the objectives of the study.

Comparative Analysis

Comparative analysis constitutes the principal methodological approach of this research. The financing mechanisms and road asset management systems of the United States, Germany, Japan, Australia, and the United Kingdom were systematically compared with current practices in Uzbekistan.

The comparison focused on several dimensions:

- sources of infrastructure financing;
- institutional governance;
- road maintenance strategies;
- lifecycle asset management;
- application of digital technologies;
- investment planning mechanisms.

The comparative evaluation facilitated the identification of international best practices applicable to Uzbekistan.

Institutional Analysis

Institutional analysis was used to examine recent reforms implemented within Uzbekistan's road sector. Particular attention was devoted to organizational restructuring, procurement reforms, centralized governance arrangements, and public investment policies introduced after 2017.

The institutional perspective makes it possible to assess how governance structures influence financing efficiency and long-term infrastructure sustainability.

Descriptive Statistical Analysis

Descriptive statistical analysis was applied to evaluate government expenditures allocated to public road infrastructure during 2022–2025.

Budget dynamics were examined by comparing annual allocations for:

- total road expenditures;
- routine maintenance;
- rehabilitation;
- reconstruction;
- capital investment.

Percentage changes and expenditure shares were calculated to identify major financing trends over the study period.

System Analysis

Road infrastructure was analyzed as an integrated socio-economic system rather than as an isolated engineering asset.

This approach considers the interaction among infrastructure financing, maintenance planning, institutional governance, investment policy, digital technologies, and transport service quality. System analysis makes it possible to evaluate how changes in one component influence the overall efficiency of road asset management.

Document Analysis

Official reports, legislative acts, strategic development programs, and publications issued by international organizations were analyzed using document analysis techniques.

This method ensured consistency between the empirical findings and existing policy frameworks while enhancing the reliability of the study.

Analytical Framework

The analytical framework adopted in this research is based on internationally accepted principles of sustainable infrastructure management. Five analytical dimensions were considered:

1. Financial sustainability, including the stability and diversification of funding sources;
2. Institutional effectiveness, referring to governance arrangements and organizational responsibilities;
3. Lifecycle asset management, emphasizing preventive maintenance and long-term cost optimization;
4. Digital transformation, focusing on the adoption of GIS, BIM, IoT, Digital Twin technologies, and Artificial Intelligence (AI);
5. Policy effectiveness, evaluated through infrastructure performance, investment efficiency, and long-term sustainability.

These dimensions provide an integrated framework for assessing both international experience and Uzbekistan's ongoing reforms.

Research Limitations

Several limitations should be acknowledged.

First, the study relies primarily on official statistical information and publicly available institutional reports. Consequently, access to some country-specific operational data used by road agencies was limited.

Second, the research emphasizes qualitative comparative analysis rather than econometric modeling. Although this approach facilitates policy interpretation, future studies may further strengthen the empirical evidence through panel data analysis or cost–benefit modeling.

Finally, the analysis concentrates on selected countries recognized for their advanced road asset management systems. Therefore, the findings should be interpreted primarily as valuable policy references for countries undergoing institutional modernization, including Uzbekistan, while acknowledging that national circumstances may vary.

ANALYSIS AND RESULTS

Sustainable financing remains one of the most critical determinants of efficient road infrastructure management. International practice demonstrates that countries rarely depend on a single financing source. Instead, they combine several complementary financing mechanisms to ensure stable investment flows throughout the infrastructure lifecycle.

Government budget allocations continue to represent the primary source of financing in many countries. However, relying exclusively on annual budget appropriations may create uncertainty in maintenance planning because funding levels are influenced by fiscal conditions and policy priorities.

To address these challenges, many developed countries have established dedicated Road Funds financed through fuel taxes, vehicle registration fees, axle-load charges, and other road-user payments. These funds provide predictable financial resources that enable road agencies to implement long-term maintenance strategies.

Public–Private Partnerships (PPPs) have also become increasingly important. PPP arrangements enable governments to attract private investment while sharing financial and operational risks. Under concession agreements, private companies frequently assume responsibility for road construction, operation, maintenance, and toll collection over extended contractual periods.

Toll road systems constitute another significant financing mechanism. Countries such as Japan and several European nations have successfully implemented user-based charging systems that simultaneously generate maintenance revenues and regulate traffic demand.

International financial institutions—including the World Bank, the Asian Development Bank, the European Investment Bank, and other multilateral development banks—also play an essential role by providing long-term financing for strategic infrastructure projects, particularly in developing economies.

These international experiences indicate that diversified financing structures substantially improve the sustainability and resilience of road infrastructure systems.

These international experiences also provide valuable policy lessons for developing countries seeking to modernize road infrastructure management systems. Rather than focusing primarily on constructing new roads, governments increasingly recognize the economic importance of preserving existing infrastructure through lifecycle-oriented investment strategies.

Table 1. Comparative Characteristics of International Road Financing and Asset Management Systems

Country	Main Financing Sources	Asset Management Approach	Digital Technologies	Key Lessons
United States	Highway Trust Fund, federal and state budgets	Pavement Management System (PMS), Life Cycle Cost Analysis	GIS, AI, Remote Sensing	Data-driven maintenance planning
Germany	Federal budget, heavy vehicle tolls	Preventive maintenance, ISO-based management	Digital asset databases	Sustainable user-pay financing
Japan	Toll expressways, government investment	Disaster-resilient lifecycle management	IoT, Digital Twin, Structural Health Monitoring	Continuous infrastructure monitoring
Australia	Government funding, PPP	Performance-based asset management	GIS, BIM	Economic optimization of maintenance
United Kingdom	Government funding, PPP	ISO 55000 integrated asset management	BIM, Digital Twin, AI	Digital transformation and strategic asset management

The comparative analysis demonstrates that successful road asset management depends not only on the amount of financial investment but also on institutional effectiveness, technological innovation, and long-term strategic planning. Countries that adopt integrated asset management systems consistently achieve higher infrastructure quality, lower maintenance costs, and greater financial sustainability.

To evaluate recent developments in Uzbekistan's road sector, government expenditure allocated to public road infrastructure during **2022–2025** was analyzed. The findings indicate a consistent increase in public investment, reflecting the government's commitment to improving transport infrastructure and strengthening national logistics capacity.

Table 2 presents the dynamics of public expenditure on road infrastructure based on official government statistics reported in the source article.

Table 2. Government Expenditure on Public Roads in Uzbekistan (2022–2025)

Indicator	2022	2023	2024	2025
Total road expenditure (trillion UZS)	4.8	5.7	6.6	7.6
Routine maintenance (trillion UZS)	2.1	2.9	3.6	4.6
Share of maintenance (%)	45	50	55	60
Construction, reconstruction, and capital rehabilitation (trillion UZS)	2.6	2.9	3.0	3.0

The data reveal a steady upward trend in overall government expenditure. Total allocations increased from UZS 4.8 trillion in **2022** to UZS 7.6 trillion in **2025**, representing an increase of approximately **58.3%** during the study period. This growth reflects the government's strategic priority of modernizing national transport infrastructure and improving the quality of road services.

The findings of this study demonstrate that sustainable road infrastructure development depends not only on increasing financial investment but also on strengthening institutional governance, adopting lifecycle-oriented asset management, and integrating digital technologies into infrastructure planning and maintenance. This conclusion is consistent with previous international studies emphasizing that infrastructure quality is influenced more by management efficiency than by the absolute level of public expenditure.

The comparative analysis reveals that developed countries have gradually shifted from reactive maintenance strategies toward proactive asset management systems. Rather than allocating substantial resources to large-scale reconstruction after infrastructure deterioration has occurred, these countries prioritize preventive maintenance supported by systematic condition monitoring and long-term investment planning. Such an approach significantly reduces lifecycle costs while improving service quality and infrastructure resilience.

The expenditure analysis presented in this study indicates that Uzbekistan has begun to follow a similar trajectory. The increasing proportion of maintenance expenditure within the total road budget suggests that policymakers increasingly recognize the economic benefits of preserving existing infrastructure assets. This transition represents an important institutional development because preventive maintenance generally generates considerably higher economic returns than delayed rehabilitation or complete reconstruction.

Another important finding concerns the diversification of financing mechanisms. International experience demonstrates that reliance exclusively on annual government budget allocations may create uncertainty in long-term infrastructure planning. Countries such as the United States, Germany, and Japan have successfully enhanced long-term planning through dedicated Road Funds, user charges, toll systems, and Public–Private Partnership (PPP) arrangements. These mechanisms provide predictable financial resources while encouraging greater operational efficiency and accountability.

In Uzbekistan, the financing system continues to rely predominantly on state budget appropriations. At the same time, increasing public investment has substantially contributed to the development of road infrastructure, while further diversification of financing sources would strengthen long-term financial sustainability. Expanding PPP projects, introducing user-based financing instruments where economically justified, and attracting greater private investment would further support infrastructure modernization while reducing fiscal pressure.

The study also highlights the growing importance of digital transformation in road asset management. International road agencies increasingly employ Geographic Information Systems (GIS), Building Information Modeling (BIM), Internet of Things (IoT) sensors, Digital Twin platforms, and Artificial Intelligence (AI) to monitor infrastructure performance and optimize maintenance planning. These technologies enable real-time condition assessment, predictive deterioration modeling, automated inspection, and data-driven investment prioritization.

Compared with these international practices, digital transformation in Uzbekistan's road sector is progressing steadily. Existing reforms have primarily focused on institutional restructuring and increasing investment capacity, while comprehensive digital asset management systems continue to evolve. Accelerating the adoption of integrated digital technologies would improve decision-making accuracy, reduce maintenance costs, increase transparency, and strengthen the efficiency of public expenditure.

The findings further suggest that road asset management should be viewed as an interdisciplinary management process rather than solely as an engineering activity. Effective infrastructure management requires coordination among economists, engineers, financial specialists, policymakers, and information technology professionals. Such integration facilitates a more rational allocation of financial resources while improving infrastructure performance throughout the asset lifecycle.

From a policy perspective, the results indicate that Uzbekistan possesses a favorable institutional foundation for the further modernization of its road sector. Recent governance reforms, increasing maintenance expenditure, and growing investment commitments provide a strong basis for implementing internationally recognized asset management standards. Continued institutional reforms, digital transformation, and the further development of sustainable financing mechanisms will strengthen the modernization of the road sector in line with international best practices.

CONCLUSION AND SUGGESTIONS

Road infrastructure constitutes one of the most valuable public assets that directly influences economic growth, regional integration, logistics efficiency, and national competitiveness. Ensuring the long-term sustainability of road networks therefore requires not only adequate financial resources but also effective institutional governance, lifecycle-oriented asset management, and the application of advanced digital technologies.

This study examined international experience in road sector financing and road asset management by comparing the practices implemented in the United States, Germany, Japan, Australia, and the United Kingdom. The comparative analysis demonstrates that successful infrastructure management depends on diversified financing mechanisms, preventive maintenance strategies, systematic asset monitoring, and evidence-based investment planning. Developed countries increasingly regard road networks as strategic national assets requiring continuous management throughout their entire service lives rather than focusing primarily on new infrastructure construction.

The analysis of Uzbekistan's recent institutional reforms indicates significant progress in strengthening road sector governance. The gradual increase in government expenditure on road maintenance, organizational restructuring, and improvements in procurement procedures **reflect** the country's commitment to modernizing transport infrastructure. The observed increase in maintenance expenditure as a proportion of total road investment suggests a gradual transition toward internationally recognized lifecycle asset management principles, consistent with the trends identified in advanced economies.

At the same time, additional opportunities remain to further strengthen the road sector. Current financing mechanisms continue to rely predominantly on annual state budget allocations, while alternative funding sources, such as dedicated Road Funds, Public–Private Partnerships (PPPs), infrastructure bonds, and broader user-based financing instruments, offer considerable potential for further development. Furthermore, the implementation of comprehensive digital asset management technologies—including Geographic Information Systems (GIS), Building Information Modeling (BIM), the Internet of Things (IoT), Digital Twin platforms, and Artificial Intelligence (AI)—can be further expanded in line with leading international practices.

Based on these findings, several policy recommendations are proposed. First, Uzbekistan should diversify infrastructure financing by expanding private sector participation and strengthening long-term financing instruments. Second, national road authorities should gradually implement the ISO 55000 Asset Management Standards to improve institutional effectiveness and investment efficiency. Third, greater emphasis should be placed on preventive maintenance supported by lifecycle cost analysis rather than on costly rehabilitation following significant infrastructure deterioration. Finally, accelerating digital transformation through integrated asset information systems and predictive maintenance technologies would substantially improve infrastructure sustainability, transparency, and decision-making quality.

Overall, the findings demonstrate that sustainable road infrastructure management requires the integration of financial, institutional, engineering, and technological approaches within a comprehensive asset management framework. The international experiences examined in this study provide valuable guidance for supporting the continued modernization of Uzbekistan's road sector while contributing to broader discussions on sustainable infrastructure governance in developing economies.

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