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THE ROLE OF INTELLIGENT TRANSPORTATION SYSTEMS IN IMPLEMENTING AUTOMATED PAYMENT SYSTEMS ON TOLL ROADS

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Abstract:
As a continuation of the recent developments in the road infrastructure sector in our country, the construction of toll roads such as the Tashkent–Samarkand and Tashkent–Andijan highways is of great importance. One of the key issues in toll road operations is the automation of payment systems for vehicles.
This article examines modern approaches to implementing automated toll collection systems and highlights the role of Intelligent Transportation Systems (ITS) in this process. The study analyzes how ITS contributes to optimizing traffic flow, simplifying the payment process, and increasing the overall efficiency of road infrastructure. Proposals and conclusions are presented based on both local and international experiences.

Keywords: Toll roads, traffic intensity, "Tashkent-Samarkand" toll road, "Tashkent-Andijan" toll road, road traffic accident, road project efficiency, intelligent transportation systems

Introduction

Main Causes of the Formation of the Key Problem in the Research

Currently, the primary issue facing highways is the increase in traffic intensity and the expansion of interregional routes. According to data from the Road Committee on the prospects of highways, the construction of toll roads such as

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the **"Tashkent – Samarkand"** and **"Tashkent – Andijan"** highways leads to an increased share of the transport network in the gross domestic product through the transportation of international transit cargo [1].

The objective of this study is to investigate the impact of constructing the toll roads **"Tashkent - Samarkand"** and **"Tashkent - Andijan"** on improving the efficiency of the public highway network within the territory of the Republic of Uzbekistan. To achieve this objective, the following tasks were addressed [2]:

- An economic method for evaluating the efficiency of toll road operations was selected;
- The economic benefits of using toll roads were assessed [3].

Along the M-39 highway "Almaty - Bishkek - Tashkent - Shakhrisabz - Termez," traffic intensity at transport hubs located along the route from Tashkent city to Samarkand city ranges from 20,000 to 62,000 vehicles per day (see Figure 1).

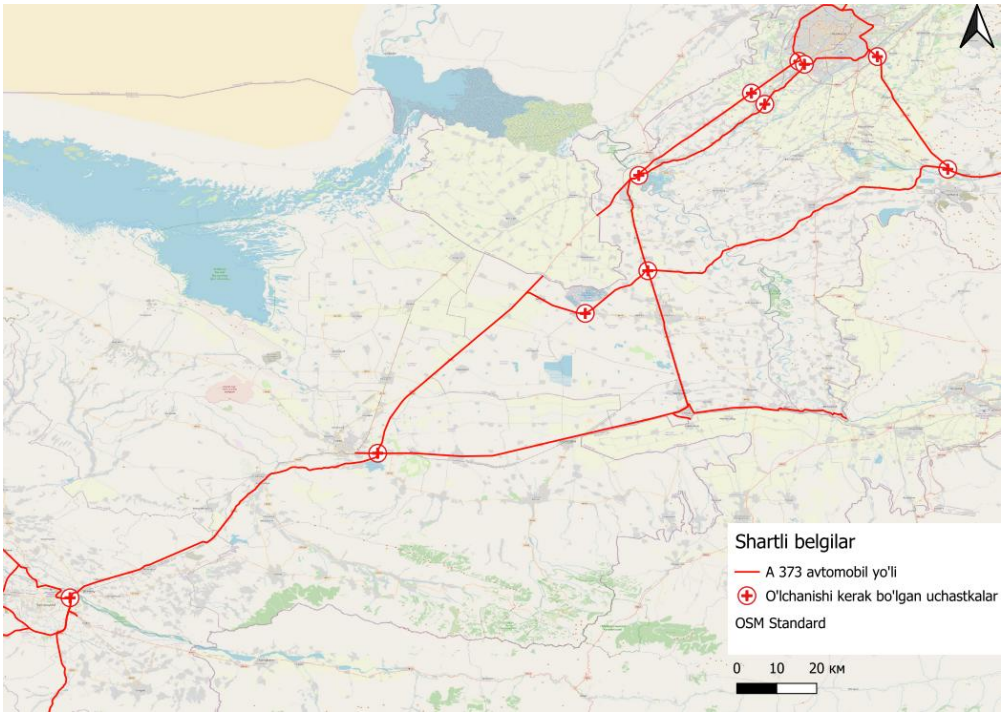

Figure 1. Transport nodes along the M-39 highway "Almaty - Bishkek - Tashkent - Shakhrisabz - Termez" between Tashkent and Samarkand have been identified for forecasting traffic intensity on the "Tashkent - Samarkand" toll road [4].

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The significance of the obtained results for the economy of the Republic of Uzbekistan is that the development of toll road infrastructure positively impacts:

- Improving transport capabilities (reducing travel time by enhancing road quality and shortening road length) [5];
- Job creation (infrastructure development helps boost economic activity in regions);
- Tourism development (improved road infrastructure makes regions more attractive and accessible to tourists).

In recent years, the experience of implementing public-private partnerships and toll roads in financing road infrastructure in the Republic of Uzbekistan has become a topical issue. For the effective operation of toll roads, automatic payment systems are essential, which are based on intelligent transport technologies. Considering the growing number of cyberattacks on electronic accounting systems, it is necessary to develop secure and fast payment systems. The role of intelligent transportation systems (ITS) in creating such secure and fast payment systems, optimizing traffic flow, simplifying payment processes, and enhancing the efficiency of toll road infrastructure is of great importance [6]. Intelligent transportation systems (ITS) refer to a set of modern technologies enabling automation of traffic and payment processes on highways, as well as real-time monitoring, control, and management. These systems specifically improve efficiency, safety, and user convenience on toll roads [7].

Improving payment systems on toll roads enhances traffic conditions and increases road throughput capacity. The study analyzes research conducted by world scientists and the practical experience of developed countries.

Currently, an increase in freight traffic on toll roads is expected. On many internationally significant roads, one-third of the traffic flow consists of freight vehicles and two-thirds of passenger vehicles [1-3]. It should be emphasized that the majority of freight delivery is directed toward the western part of the country, indicating transit shipments from China to Europe. Additionally, it is related to exporting goods to Kazakhstan and other Central Asian countries [4,5].

The construction of toll roads is actively developing in many countries due to several advantages [6-7]:

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- Reduction of travel time on highways;
- Shorter distances on toll sections compared to alternative routes;
- Higher speeds enabled by superior road quality on toll sections;
- Convenience of travel thanks to developed infrastructure (fuel stations, rest areas, cafes, etc.).

Analysis of scientific research shows that the issues of toll road placement and design have been sufficiently studied [8].

However, problems related to toll pricing, location of payment points, and assessment of traffic safety on toll roads—factors ultimately affecting economic efficiency—are not well understood and require further research [9].

Toll roads can be economically viable if revenues from tolls exceed construction and operational costs. This is particularly true for heavily trafficked routes where drivers are willing to pay for high-quality roads and reduced travel times.

Objective of the Research:

To assess the economic efficiency of the toll roads "Tashkent - Samarkand" and "Tashkent - Andijan" by improving the efficiency of the public highway network in the Republic of Uzbekistan.

Main Part:

The main approaches to evaluating the economic efficiency of toll roads involve analyzing various aspects related to their construction, operation, and economic impact [10]:

1. Cost-benefit analysis (including construction, operation, maintenance costs, and benefits such as reduced travel time, lower fuel costs, and improved traffic safety).
2. Socio-economic analysis (impact of toll road emergence on society, creation of additional jobs, and improvements in transport infrastructure).
3. Public-private partnership evaluation (assessment of the effectiveness of attracting private investment in construction and usage, as well as identifying potential risks).

These methods assist in making informed decisions about the feasibility of toll road construction and their impact on the economy and society. The evaluation

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involves comparing all costs with expected benefits to determine whether the benefits outweigh the costs and assess the project's economic feasibility.

A comparative analysis was conducted to assess the potential savings of toll road usage relative to alternative free routes. Traffic flow forecasting on the "Tashkent - Samarkand" toll section is carried out based on analyzing the expected number of vehicles between interconnected population centers and modeling their travel routes [11].

Traffic intensity forecasting considers distances between interconnected points, travel time costs, and travel convenience.

The determination of intensity on specific road segments between connected points follows the methodology presented in guidelines for forecasting traffic intensity on highways [12]:

$$N_{ij} = \frac{P_p * k_c * Q_л * V_л * \tau_л * К_л}{1000 * L_{пр}^2} + \frac{P_p * k_c * Q_а * V_а * \tau_а * К_а}{1000 * L_{пр}^2} + \frac{P_p * k_c * Q_г * V_г * \tau_г * К_г}{1000 * L_{пр}^2} \quad (1,1)$$

Here,

P_p – population of the studied interconnected settlements, persons;

K_c – an integral coefficient reflecting the relationship between the analyzed relevant objects, considering the administrative-economic status of the settlements;

Q_л – current density of motor vehicles, vehicles per 1000 people;

V_л – average speed of light vehicles, km/h;

τ_л – average daily usage duration of light vehicles, hours/day;

K_л – integral coefficient of operational activity of passenger transport;

L_пр – approximate length of the travel section between interacting objects, km;

Q_a – density of bus fleet distribution at the boundaries of settlements, vehicles per 1000 people;

V_a – average speed of buses, km/h;

τ_a – average daily operating duration of the bus fleet, hours/day;

K_a – integral coefficient of operational activity of the bus fleet;

Q_г – density of freight transport distribution at the boundaries of settlements, vehicles per 1000 people;

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V_г – average speed regime of freight transport, km/h;
τ_г – average daily operation time of freight vehicles within the daily cycle, hours/day;
K_г – integral indicator determined by the operational level of freight vehicles.
The population calculated for each pair of interconnected settlements under study is based on the ratio of the number of residents in each city:

- If the population ratio between the larger city (**P_max**) and the smaller city (**P_min**) does not exceed 7.38, it is determined using the following formula (1,2):

$$P_p = (\ln\frac{P_{max}}{P_{min}}) + 2) * P_{min} \quad (1,2)$$

If the condition is not met, the population for the studied pair of settlements is determined by the following formula (1.3):

$$P_p = 4 * P_{min} \quad (1,3)$$

The population in the cities along the "Tashkent - Samarkand" toll road under study was determined (Table 1) [8].
The integral indicator of the operational activity of passenger transport on weekdays is determined by the following formula (1.4):

$$К_л = 1 – (D_H + D_p) \quad (1,4)$$

Here,
D_H – the share of vehicles accounted for in the statistics but with limited use due to technical malfunctions;
D_p – the share of vehicles used for relocating to recreational areas during the spring-summer-autumn seasons.
It is necessary to determine the average daily duration of active operation of the bus fleet (1.5):

$$τ_л = T_{Ha} - 2 \quad (1,5)$$

Here,
T_Ha – the duration of active operation of the bus fleet per shift, hours.
It is necessary to determine the integral indicator of the operational activity of the bus fleet (1.6):

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$$К_а = Г_а * К_{ва} \quad (1,6)$$

Here,

Г_а – the integral indicator of the bus fleet's readiness to perform scheduled routes;

К_ва – an integral indicator reflecting the share of vehicles that depart according to the approved timetable [13].

1 – table "Population size in settlements."

№	**Name of settlement:**	Number of inhabitants
1	Zangiota district	169 940
2	Yangiyo‘l city	203 891
3	Chinoz city	144 785
4	Olmazor city	66 458
5	Baxt city	27 000
6	Guliston city	99 300
7	Oqoltin city	51 300
8	Sardoba district	20 700
9	Jizzakh city	188 300
10	G‘allaorol city	128 100
11	Bulung’ur city	189 600
12	Jomboy district	180 400

The congestion on the studied road section is directly related to the demographic density of the neighboring areas. Transport attraction zones, parallel roads, and all indicators influencing the distribution of traffic flow were examined. Forecasting traffic parameters (traffic intensity and speed) is carried out using an integral modeling method that takes into account the interactions between all nodes of the transport network [14].

The automatic toll collection system (ETC – Electronic Toll Collection) on toll roads ensures that drivers can make payments automatically without stopping as they pass through designated points. This system is based on RFID (Radio Frequency Identification), automatic number plate recognition cameras (ANPR), sensors, and other information technologies (see Figure 2).

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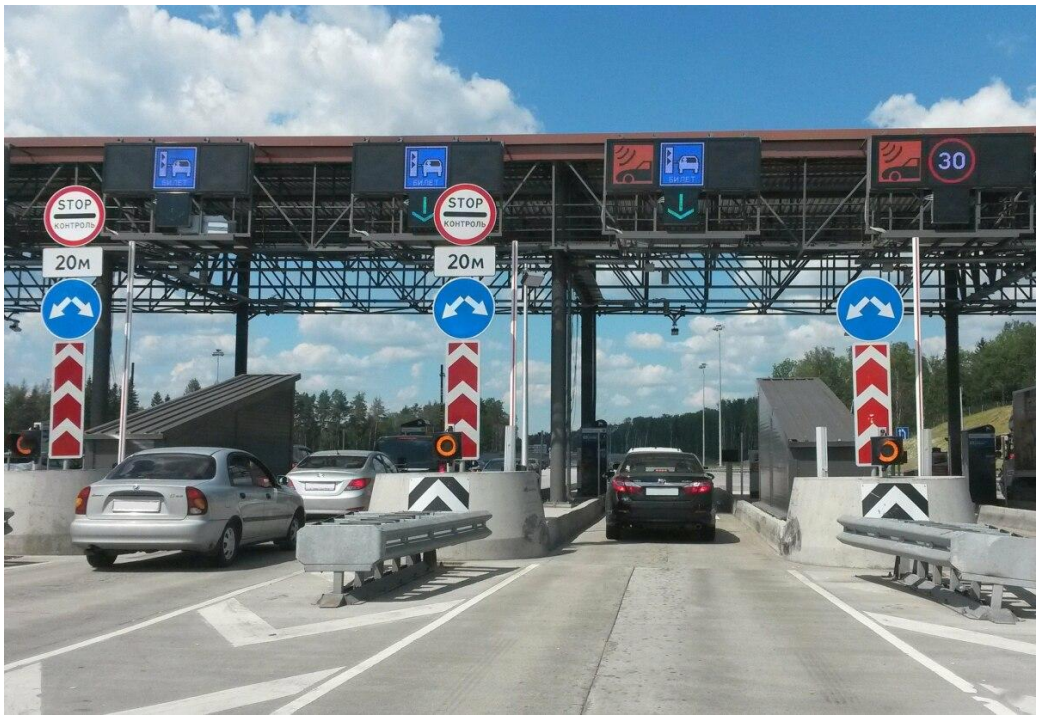

Figure 2. Practical application of automatic vehicle identification and registration systems on toll roads

In countries such as China, the USA, South Korea, and European nations, toll road systems are fully automated. For example, in South Korea, payments are made using RFID-based T-Money cards. The USA's EZ-Pass system automatically identifies the payment status of vehicles.

In Uzbekistan, transport infrastructure is gradually being digitized. Through the implementation of Intelligent Transportation Systems (ITS) on toll roads, the following benefits can be achieved:

- Reduction of human factors in payment processes
- Continuous traffic flow without stopping
- Increased budget revenues
- Enhanced convenience for road users

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Results and Discussion

The overall advantages of using toll highways for vehicles were calculated. Part of the road falls under category Ib: it is fully equipped with a lighting system, and there are no intersections with traffic lights or other roads along its entire length.

Conclusion:

Implementing automatic toll collection systems on toll roads is a requirement of the modern era. For the successful operation of this system, full integration of intelligent transportation systems is necessary. Adapting ITS technologies to the national road infrastructure in Uzbekistan will lead not only to economic efficiency but also to improved road traffic safety.

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