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Proceedings of International Conference on *Emerging Trends and Challenges in Sustainable Transportation*

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September 15-16th, 2025

INTERNATIONAL CONFERENCE

“EMERGING TRENDS AND CHALLENGES IN SUSTAINABLE TRANSPORTATION”

Held in the frame of Erasmus+ CBHE “SPHERE - Sustainable Transportation within the framework of a green deal” project
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Conference sections:

1. **Sustainable transportation and decarbonization strategies**
2. **Urban mobility and transition to electric transportation**
3. **Innovations in sustainable transportation education and research**
4. **Legal frameworks, policies and regulations for sustainable transportation**

Tashkent-2025

This document serves as proceedings from the INTERNATIONAL CONFERENCE "EMERGING TRENDS AND CHALLENGES IN SUSTAINABLE TRANSPORTATION". The conference was held in Turin Polytechnic University in Tashkent in the frame of Erasmus + CBHE project called "Sustainable transportation within the framework of a green deal" (acronym SPHERE) on September 15-16th, 2025. Tashkent:2025.

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PREFACE

Dear distinguished guests, respected colleagues, partners, and participants,

It is my great pleasure to welcome you to the **International Conference "Emerging Trends and Challenges in Sustainable Transportation"**, hosted by **Turin Polytechnic University in Tashkent** within the framework of the **Erasmus+ CBHE project "Sustainable Transportation within the Framework of a Green Deal (SPHERE)"**.

Today, as transportation systems around the world undergo rapid transformation, sustainable mobility stands at the forefront of global scientific and technological development. The shift toward energy-efficient, environmentally responsible, and smart transport solutions is not only a technological necessity, but also a strategic imperative for social well-being, economic progress, and the preservation of our planet.

Our conference brings together leading experts, researchers, industry representatives, and policymakers who share a common purpose: to exchange ideas, explore innovative solutions, and advance the science and practice of sustainable transportation. We are honored to collaborate with our esteemed international partners and grateful for the strong support of the **European Union and the Erasmus+ program**.

Through the collective efforts represented here today, we reaffirm our commitment to fostering innovation, promoting academic excellence, and supporting scientific research that addresses real challenges in mobility, decarbonization, road safety, electric and autonomous vehicles, infrastructure development, and intelligent transportation systems.

I am confident that the knowledge shared and networks formed during this conference will contribute significantly to the global movement toward greener, safer, and smarter transportation systems. Let this gathering become a platform for constructive discussions, meaningful partnerships, and groundbreaking ideas that will shape the future of sustainable mobility.

I extend my sincere gratitude to all organizers, speakers, and participants for contributing to this event, and I wish you productive sessions, fruitful dialogue, and great success in your research endeavors.

Thank you and welcome to the conference.

Rector, Turin Polytechnic University in Tashkent

DSc., Associate professor O.A. Tuychiev

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SUSTAINABLE TRANSPORTATION AND DECARBONIZATION STRATEGIES.

Influence of traffic volume and heavy vehicle proportion on pollutant concentrations on multi-lane urban streets

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ABSTRACT

This paper presents the outcomes of field-based monitoring of air pollutant concentrations-including carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2)-conducted along straight, unobstructed urban street segments in Tashkent featuring 4, 6, and 8 traffic lanes. The measurements were performed during the spring of 2025 under stable and favorable meteorological conditions to ensure uniform data quality across all observation points.

The primary focus was on assessing how total traffic volume and the share of heavy vehicles (e.g., trucks) within the traffic stream influence pollutant levels. The results demonstrated a strong and consistent positive correlation: as vehicle flow increases-particularly with a greater proportion of heavy-duty vehicles-the concentrations of NO and NO_2 rise sharply, often exceeding both national and international ambient air quality standards. While CO and SO_2 showed comparatively milder fluctuations, threshold exceedances were still evident under conditions of high traffic intensity and elevated truck share.

These outcomes underscore the disproportionate impact that heavy vehicles exert on urban air pollution levels. The findings provide a scientific foundation for urban environmental policy and traffic management strategies aimed at reducing emissions. Potential measures include restricting truck access during peak traffic hours, encouraging cleaner vehicle technologies, and incorporating vegetative buffer zones. This study offers valuable insight into the emission dynamics of multi-lane roadways

in densely developed urban environments and supports data-driven decision-making for sustainable urban planning.

Key words: Urban air quality, traffic emissions, heavy-duty vehicles, vehicle density, multi-lane roadways, pollutant monitoring, CO, NO, NO_2, SO_2, environmental impact.

INTRODUCTION

As motorization intensifies in major urban centers, air pollution from vehicular emissions has emerged as one of the most pressing environmental challenges. Vehicles powered by fossil fuels are among the primary contributors to degraded air quality, especially along heavily trafficked corridors of the urban road network.

The environmental impact of vehicle emissions varies depending on vehicle type. Notably, heavy-duty vehicles (HDVs) emit substantially more pollutants than passenger cars, making their proportion within the traffic stream a critical factor in evaluating urban air quality.

A growing body of research has established the importance of traffic intensity and the share of heavy vehicles in shaping pollutant concentrations on multi-lane roads [1–7]. Several studies have demonstrated that heavy vehicle traffic is more closely linked to negative health outcomes-such as impaired lung function in children-than overall traffic volume [1, 2]. Additionally, fine-scale modeling of urban air pollution reveals significant spatial heterogeneity, with higher pollutant levels near arterial roads and areas influenced by wind patterns [3]. Elevated traffic volumes, particularly involving trucks, are associated with increased emissions of nitrogen oxides (NO and NO_2) and particulate matter (PM2.5), posing acute environmental and health risks in densely populated cities like Beijing [4].

The impact of diesel-powered freight transport is particularly notable. For example, research conducted in Hunts Point, New York, found that each additional 100 heavy trucks per hour increased elemental carbon concentrations by approximately 1.69 $\mu g/m^3$ [5]. Similarly, truck-dominated traffic flows have been linked to increased NOx emissions and, in some cases, shifts in CO levels [6]. Exposure to heavy-duty traffic is also associated with elevated levels of ultrafine and particulate pollutants, further exacerbating health risks in urban zones with intense freight activity [7].

While numerous studies have assessed how traffic volume affects urban air pollution, fewer have investigated the specific contribution of heavy vehicle share, particularly in the context of streets with differing lane configurations. Existing research often lacks a detailed breakdown of pollutant behavior across multiple lanes counts or intra-road variations.

The present study addresses this gap by examining how air pollutant concentrations (CO, NO, NO_2, SO_2) vary with traffic intensity and the percentage of heavy vehicles on straight, smooth urban roads in Tashkent, configured with 4, 6, and 8 lanes. Field measurements were conducted under favorable springtime weather conditions, and only road segments with uniform, defect-free pavement were selected. This controlled approach helped isolate the effects of traffic structure while minimizing interference from surface irregularities or environmental confounders.

METHODS

The study was carried out on selected urban streets in Tashkent featuring 4-, 6-, and 8-lane configurations. The analyzed segments included: Sarikul Street, Eski-Sarikul Street, Beruniy Street, Nurafshon Street, Nukus Street, Amir Temur Avenue, Shakhrisabz Street, Makhtumkuli Street, Alisher Navoi Street, Mukimiy Street, Shota Rustaveli Street, Fargona Yuli Street, and Mirzo Ulugbek Street.

To ensure consistency and reliability of the measurements, the selection of segments was guided by the following criteria:

- All road sections had asphalt concrete pavements free from major defects such as potholes, longitudinal or transverse cracks, and surface deformations.

- Pavement smoothness was verified through both visual inspection and instrumental assessment, ensuring minimal impact from microrelief.

- All measurements were conducted in April 2025, during the spring season, under stable meteorological conditions-specifically, clear weather, light wind, no precipitation, and ambient temperatures between +15 °C and +25 °C.

- Only straight road segments without traffic signals, intersections, or significant topographic variations were included.

The monitoring focused on measuring concentrations of four key air pollutants: carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). A Harwest E4000 portable gas analyzer was used for this purpose, with the sensor placed at an approximate height of 1.5 meters-corresponding to the average human breathing zone near the roadside.

During each monitoring session, the following traffic parameters were also recorded:

- Traffic intensity, expressed in vehicles per hour, determined through video analysis and manual vehicle counts;

- Proportion of heavy-duty vehicles, classified manually during observation.

- Average traffic speed, estimated using time-distance analysis based on video footage and stopwatch timing.

Measurements were primarily performed during peak morning and daytime hours, with each observation period lasting at least two hours. The data collected from each session were averaged to produce representative values.

Subsequently, the dataset was grouped according to the following categories:

- Number of lanes on the measured road segment (4, 6, or 8);

- Heavy vehicle shares, classified in 1% intervals (0–1%, 1–2%, ..., up to 9–10%);

- Pollutant type (CO, NO, NO_2, SO_2).

To examine the relationship between pollutant concentrations, traffic volume, and heavy vehicle share, scatter plots with linear regression trend lines were generated.

This dual visual and statistical approach facilitated a clearer interpretation of correlations between emissions and traffic characteristics.

RESULTS AND DISCUSSION

Field measurements and subsequent analysis revealed clear and consistent dependencies between air pollutant concentrations and key traffic parameters, notably vehicle intensity and the share of heavy-duty vehicles. The findings are illustrated through a series of graphs and tables to provide both visual and quantitative insights.

Figure 1 presents the relationship between carbon monoxide (CO) concentration and traffic intensity for road segments with 4, 6, and 8 lanes, categorized according to varying truck proportions.

Influence of traffic volume and heavy vehicle proportion on pollutant concentrations on multi-lane urban streets

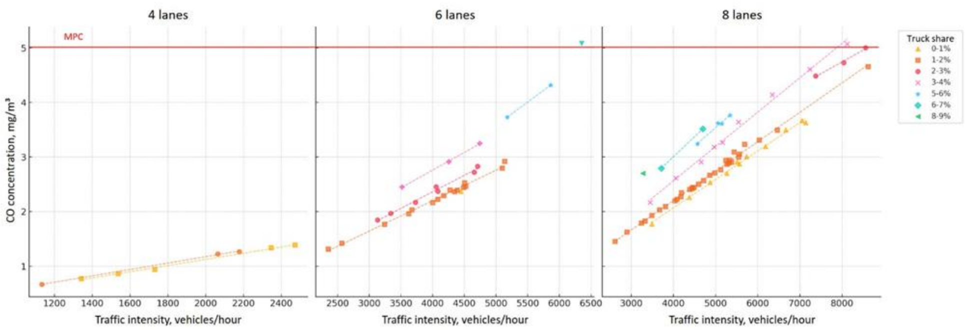

Figure 1. Relationship between carbon monoxide (CO) concentration and traffic intensity across urban street segments with different lane configurations

Comparable trends were identified for the other pollutants; Figures 2 to 4 demonstrate the corresponding patterns for nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2).

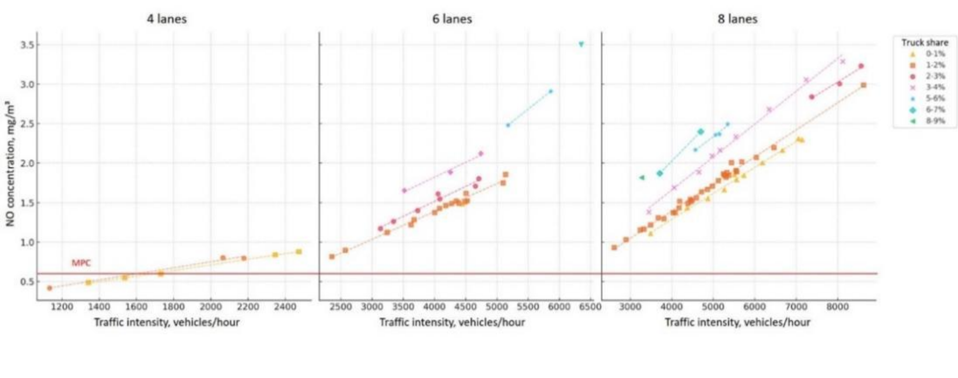

Figure 2. Relationship between nitric oxide (NO) concentration and traffic intensity on urban roads with varying lane counts

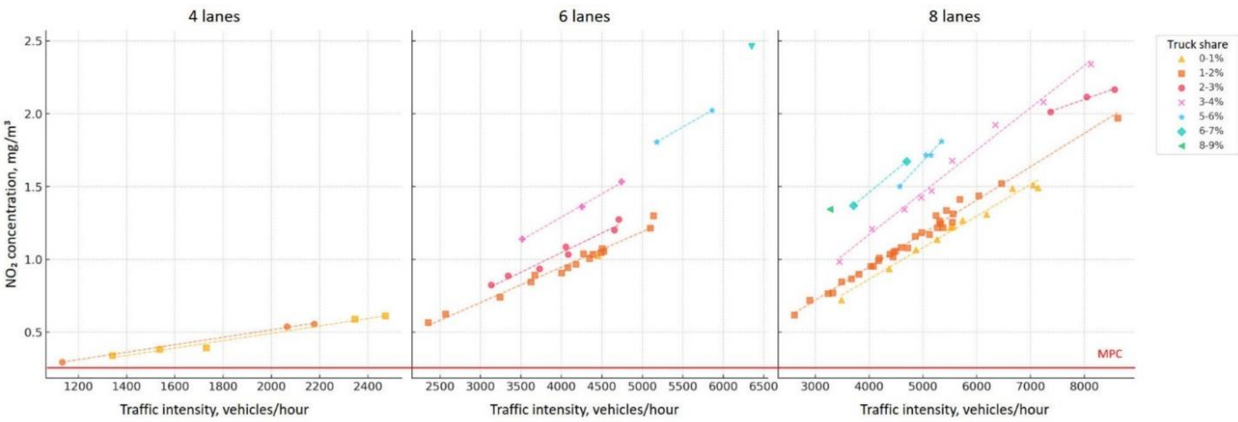

Figure 3. Relationship between nitrogen dioxide (NO_2) concentration and traffic intensity across multi-lane urban roads

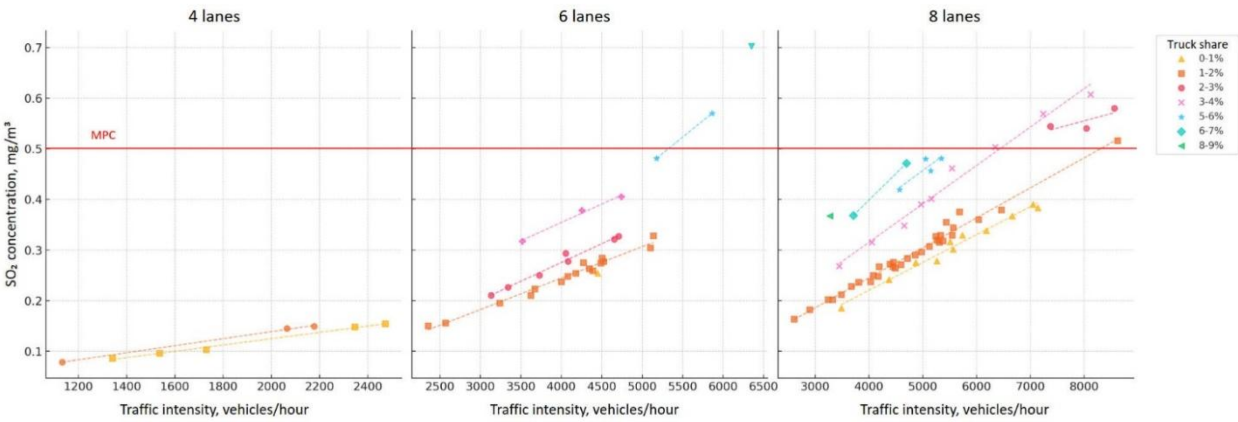

Figure 4. Relationship between sulfur dioxide (SO_2) concentration and traffic intensity across urban roads with 4, 6, and 8 lanes

Key Findings:

- Increasing traffic intensity is strongly associated with a progressive rise in concentrations of CO, NO, NO_2, and SO_2 across all multi-lane street types.

- CO concentrations show a gradual increase with traffic load but generally remain within the maximum permissible concentration (MPC) of 5.0 mg/m³. However, exceedances are recorded on 8-lane streets where both vehicle flow and truck share are high.

- For SO_2 (MPC = 0.5 mg/m³), values are often close to the threshold. Exceedances were observed primarily on segments with high heavy vehicle presence, particularly on 6- and 8-lane roadways.

- The most critical results relate to NO and NO_2. Their concentrations consistently surpass their respective MPCs of 0.6 mg/m³ and 0.085 mg/m³, even under moderate traffic conditions. These exceedances are frequent and substantial, underlining the significant environmental hazard posed by nitrogen oxides in dense urban traffic.

Table 1. Average concentrations of air pollutants (CO, NO, NO_2, SO_2) at different heavy vehicle share intervals across multi-lane urban roads

Number of lanes	Share of heavy vehicles, %	Avg. traffic intensity, veh/h	CO, mg/m³	NO, mg/m³	NO_2, mg/m³	SO_2, mg/m³
4	1-2	1886	1.056	0.669	0.463	0.117
4	2-3	1792	1.049	0.669	0.462	0.124
6	0-1	4449	2.367	1.484	1.024	0.254
6	1-2	4030	2.214	1.397	0.953	0.246
6	2-3	3959	2.334	1.499	1.034	0.272
6	4-5	4173	2.869	1.885	1.344	0.367
6	5-6	5521	4.022	2.694	1.914	0.526
6	7-8	6351	5.081	3.501	2.461	0.702
8	0-1	5623	2.911	1.819	1.215	0.309
8	1-2	4734	2.595	1.641	1.115	0.288
8	2-3	7992	4.737	3.024	2.097	0.555
8	3-4	5505	3.508	2.285	1.605	0.429
8	5-6	5031	3.556	2.346	1.685	0.459
8	6-7	4205	3.153	2.133	1.050	0.420
8	8-9	3276	2.699	1.815	1.344	0.367
etc.	—	—	—	—	—	—

Note: The table provides a representative subset of the full dataset, which encompasses a comprehensive range of truck share intervals (from 0–1% to 8–9%) and traffic intensities varying from 1,000 to 9,000 vehicles per hour.

The results clearly demonstrate that pollutant concentrations are strongly influenced by traffic intensity and the proportion of heavy-duty vehicles within the flow. Across all analyzed street types, increases in vehicle flow were accompanied by higher concentrations of CO, NO, NO_2, and SO_2, confirming the widely accepted principle that emission levels scale with vehicle volume.

However, this study goes further by incorporating lane configuration (4, 6, and 8 lanes) and traffic composition, offering a more nuanced understanding of how emissions behave under varying urban traffic conditions.

At constant traffic intensity, the data show that:

- Higher shares of heavy vehicles are consistently associated with elevated pollutant concentrations;

- Nitric oxide (NO) and nitrogen dioxide (NO_2) were the most sensitive indicators, with their values persistently exceeding maximum permissible concentrations (MPCs) across nearly all segments;

- Sulfur dioxide (SO_2) and carbon monoxide (CO) also exhibited upward trends with increasing truck share, though exceedances were less uniform:

- For CO (MPC = 5.0 mg/m^3), exceedances occurred only under combined conditions of high traffic and high truck proportion;

- For SO_2 (MPC = 0.5 mg/m^3), violations were recorded in approximately 50% of the scenarios, indicating the need for closer monitoring.

These patterns can be attributed to the higher specific fuel consumption and emission factors of heavy-duty vehicles, which makes their environmental footprint disproportionately large even when their share in the flow is modest.

Moreover, when comparing streets with different lane counts but similar traffic conditions, 8-lane roads consistently showed higher average pollutant concentrations than 4- and 6-lane roads. This may reflect both higher absolute vehicle volumes and reduced dispersion capacity due to complex traffic structures or built-up surroundings, especially in wide corridors.

CONCLUSION

This study confirmed robust and consistent relationships between ambient air pollutant concentrations and key traffic flow parameters on multi-lane urban roads in Tashkent.

Main conclusions include:

1. Pollutant concentrations (CO, NO, NO_2, SO_2) systematically increase with rising traffic intensity, regardless of whether the roadway consists of 4, 6, or 8 lanes. This reinforces the well-established link between vehicle volume and emission levels.

2. The proportion of heavy-duty vehicles within the traffic stream emerged as the most influential factor affecting pollution levels. At identical traffic volumes, areas with a higher truck share exhibited substantially elevated concentrations, particularly for NO and NO_2.

3. Among all road types, 8-lane corridors showed the highest average pollutant levels, likely due to: greater cumulative traffic volumes; a higher density of freight transport vehicles.

In most cases, CO concentrations remained within regulatory limits (MPC = 5.0 mg/m^3). However, both NO and NO_2 consistently exceeded their respective maximum permissible concentrations (0.6 mg/m^3 and 0.085 mg/m^3) across a majority of monitoring sites. These findings underscore the heightened environmental and public health risks posed by nitrogen oxides in dense urban traffic environments.

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Design of sustainable transport road infrastructure in the city of Tashkent

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ABSTRACT

This article analyses modern approaches to designing sustainable transport infrastructure, taking into account environmental, economic and social factors. Based on international experience, the author examines the factors that ensure the stability of transport systems and provides recommendations that can be applied in Uzbekistan. The article reviews international research and engineering solutions, presenting relevant conclusions.

Key words: Sustainable transport, road infrastructure, design, urban planning, ecology, transport system, integration.

INTRODUCTION

The rapid population growth that has been observed in recent years has resulted in a marked increase in car usage. This, in turn, engenders considerable challenges for the environment, society, and the economy. Consequently, the design of sustainable transport road infrastructure has become a pressing issue worldwide.

In particular, the population of the Republic has now exceeded 37.8 million. [1]. The National Statistics Committee database notes that as of January 1, 2024, there are a total of 4,020,744 vehicles owned by individuals in the Republic of Uzbekistan, and among the regions, the largest number of vehicles is in the city of Tashkent (624,022), as well as in Samarkand (448,702) and Tashkent (439,660) regions [2], and this is one of the main sources of many problems, such as negative environmental impacts, traffic jams, accident risks, noise, and an increase in exhaust gases (CO2).

Nevertheless, the transport system constitutes an integral component of human activity, exhibiting a direct correlation with economic development, social integration, and environmental sustainability. Consequently, the issue of designing sustainable transport road infrastructure has become an integral part of not only urban planning, but also the development of ecology, economy, and society.

It is evident from international experience that transport infrastructure, developed on the basis of a modern approach, has the potential to enhance efficiency of movement and play a significant role in the global effort to combat climate change. The present article examines the essence of sustainable transport infrastructure, basic design principles, components, international experience, the current situation in Uzbekistan, problems, and proposals for their solution.

The primary objective of designing sustainable transport road infrastructure is to establish a safe and comfortable transport environment for all users without causing harm to the environment.

LITERATURE REVIEW

International research on the concept of sustainable transport, including: Automobile transport is a mode of transport that offers significant advantages over other modes of transport. These advantages include convenience and flexibility to individual needs [3], As a consequence, a substantial global network of road infrastructure is currently in operation, and it is anticipated that this will increase by 2050 [4]. and these infrastructures have a significant impact on the environment at all stages of their life cycle, that is, in the process of construction, use and maintenance, including: consumption of natural resources, exhaust gases in the air, traffic noise, water pollution, negative impact on land use or green nature [5]. Moreover, the transport sector is responsible for the production of 32% of global exhaust gases, including 75% of these emissions from road transport. The exhaust gases in question consist of carbon dioxide, methane and nitrogen oxide [6]. Conversely, the process of road construction has been demonstrated to generate a substantial volume of waste, thereby exerting a deleterious effect on the natural environment. Consequently, the construction, operation and maintenance of roads exerts a substantial influence on climate change [7]. Moreover, the utilisation of road transport has been demonstrated to engender adverse social consequences. For instance, the elevated mortality rate resulting from road traffic accidents on a global scale serves as a salient illustration of this phenomenon. Globally, approximately 1.19 million people perish on an annual basis as a consequence of road traffic accidents. It is estimated that up to 50 million people are injured, with the majority of these cases resulting in disability [8]. In 2024, a total of 9,364 road traffic accidents were officially recorded in Uzbekistan. Of these, 3,045 (32.5%) involved vehicles engaged in freight and passenger transportation [9].

In order to resolve the aforementioned issues, it is imperative that the primary focus of road design is directed towards the establishment of sustainable transport systems.

METHODS

The present study draws upon international research on the concept of sustainable transport, and analyses the stages of construction, operation and maintenance of road infrastructure. The primary methodological approaches employed in the article are outlined as follows:

- Environmental analysis: The impact on the consumption of natural resources, exhaust gases in the air, traffic noise, and water resources.

- Socio-economic analysis: Citizen safety, road accidents, access to public transport, construction and operating costs, economic efficiency indicators.

RESULTS

One of the principal elements of sustainable transport infrastructure is the development of the public transport system. The judicious configuration of public transport networks can serve as a convenient and cost-effective substitute for private vehicles, thereby contributing to the reduction of traffic congestion and atmospheric emissions. It is imperative that the proposed infrastructure encompasses comprehensive bus and train routes, in addition to modern stations and terminals that prioritise accessibility for all users, including those with disabilities. Notably, this project represents the inaugural instance of a comprehensive reconstruction of a section of Shota Rustaveli Street, spanning 6.5 kilometres, being undertaken in the city of Tashkent. The project encompasses the construction of a dedicated bus lane, and the associated construction and installation works are currently in progress (Pic. 1). The implementation of such a solution has the potential to enhance the attractiveness of public transport, thereby ensuring its efficient and unobstructed operation.

Figure 1. Project thumbnail

Following reconstruction, the entire street will comprise three identical lanes for transport, excluding a dedicated lane, a parking lot, and a bicycle path. Concurrently, the bands are widened. It is estimated that the velocity of both private and public transportation should be augmented to approximately 30 km/h, while the accident rate is predicted to decline by 25%. The anticipated total economic impact of the reconstruction is estimated to be $4.2 million per annum. It is anticipated that approximately 500 designated parking spaces will be introduced to the street.

It is imperative to acknowledge the significance of ensuring the safety and convenience of bicycle and pedestrian paths as a pivotal component of sustainable transport infrastructure. It is imperative that these roads be segregated from vehicular traffic and methodically incorporated into the overarching transport network. The promotion of active modes of transport, such as cycling and walking, by urban planning authorities can result in a number of benefits for city dwellers. These include the reduction of traffic congestion, the improvement of air quality, and the promotion of a healthy lifestyle.

The establishment of an efficient and reliable electric vehicle charging infrastructure is also of crucial importance for sustainable transportation. In order to encourage the acceptance of electric vehicles, it is essential to establish a well-distribution network of charging stations that are easily accessible to urban areas and can facilitate rapid charging of vehicles. Furthermore, the incorporation of renewable energy sources within the charging infrastructure will contribute to a reduction in the carbon emissions of electric vehicles.

ANALYSIS

Based on the above results, the following analyses were conducted:

- Environment: Reduction of exhaust gases, improvement of urban air quality.

- Socio-economic: Increase in the number of public transport users, improvement of transport safety, efficiency of construction costs.

These analyses allow us to show the experience of the city of Tashkent as a model for other cities of the republic.

DISCUSSION

One of the important aspects of sustainable transport road infrastructure is the development of public transport in busy cities, the expansion of pedestrian and bicycle paths, improving their operating conditions, and supporting electric vehicles. The project implemented in Tashkent has become an important step in optimizing transport, increasing safety, and reducing the environmental burden.

It is also necessary to increase the number of convenient charging stations for electric vehicles and the use of renewable energy sources. This infrastructure serves to ensure environmental sustainability.

CONCLUSION

The development of sustainable transport infrastructure is imperative for a green future. This includes the planning and creation of effective systems that minimise environmental damage. This includes measures such as increasing the capacity of public transport systems, constructing dedicated bicycle infrastructure, and establishing pedestrian-friendly walkways. Investment in these initiatives has the potential to reduce carbon emissions, whilst also promoting health and wellbeing, and reducing traffic congestion. Moreover, by prioritising the creation of sustainable transport infrastructure, it is possible to achieve the creation of efficient, convenient, and environmentally friendly modes of transport, thereby minimising the impact of transport systems on the environment.

The initial steps in this direction are being taken in the cities of Uzbekistan. However, genuine sustainability can be achieved through projects grounded in systemic, scientifically based, and urban approaches. This necessitates the provision of clean air, safe movement, and a comfortable living environment for future generations.

In order to establish a sustainable transport infrastructure in Uzbekistan, the following recommendations are proposed:

- The priority of public transport should be increased. This may be achieved by the introduction of new metro lines, electric buses and trams.
- Green infrastructure should be created. This may be achieved by the creation of safe bicycle and pedestrian paths. These should be included in the plans of each city.
- Electric transport infrastructure should be developed. This may be achieved by the expansion of charging station networks and the introduction of tax benefits to encourage the purchase of electric vehicles.

In conclusion, the development of sustainable transport infrastructure is imperative for the creation of a more environmentally friendly and efficient transport system. This encompasses the presence of well-developed public transport systems, safe pedestrian and bicycle pathways, and dependable electric vehicle charging infrastructure. By allocating resources towards the development of sustainable transport infrastructure, urban areas can achieve a reduction in traffic congestion, an enhancement in air quality, and an improvement in the overall quality of life for their inhabitants.

ACKNOWLEDGEMENT

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On dynamics of EV/HEV market development in Uzbekistan

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ABSTRACT

This article examines Uzbekistan's 2018–2025 EV and HEV markets. Imports increased exponentially from 13 units in 2018 to over 41,000 in 2024, demonstrating the importance of government incentives in adoption. Since 2019, customs tariffs, excise taxes, and VAT have been waived, lowering ownership costs. Road and recycling fees have also been eliminated. Tashkent accounts for nearly 80% of the national fleet of electric vehicles, revealing regional differences in purchasing power, infrastructure, and customer awareness. The 2024 BYD–UzAuto joint venture (BYD Uzbekistan Factory) began domestic electric vehicle production and marked a shift from imports to industrial localization. Despite these advances, regional charging infrastructure, grid capacity, and recycling and certification procedures remain issues. With regulatory assistance, infrastructure development, and sector diversification, Uzbekistan might lead Central Asia in electromobility.

Keywords: Electric vehicles; Hybrid electric vehicles; Market dynamics; Uzbekistan; Government incentives; Charging infrastructure; Industrial localization; Sustainable mobility; Central Asia

INTRODUCTION

Sustainable and low-carbon mobility is revolutionizing the global auto industry. This move relies on electric vehicles (EVs) and hybrid electric vehicles (HEVs) to reduce greenhouse gas emissions, improve urban air quality, and reduce fossil fuel use. Due to battery technology, production costs, and government incentives, many nations have adopted electric vehicles quickly in the previous decade. [1,2]. The global growth of electric vehicles, especially in Uzbekistan, offers an environmentally friendly transportation option. The growth of this industry requires solving problems, creating solutions, and improving infrastructure. Many industrial and social sectors of the State must work together to create new markets for innovative products to build electric car infrastructure.

The Uzbek government has implemented several incentives to accelerate electric vehicle usage. Electric cars are cheaper than ICE cars since they are exempt from customs and excise taxes since 2019 [3]. More steps were implemented in 2022, such as a VAT exemption for EV imports and abolition of road and recycling fees that increase automobile ownership expenses. The import tax exemption for electric car charging equipment and replacement parts encourages private companies to invest in charging infrastructure. These efforts are part of the national "Green Economy Transition Strategy 2019–2030" [4] which sets goals for electric car use and energy and infrastructure development. These incentives create a legislative framework that makes Uzbekistan a Central Asian leader in electric vehicle policies[5,6].

MARKET DYNAMICS OF THE EV/HEV SECTOR IN UZBEKISTAN

The electric vehicle (EV) market in Uzbekistan has experienced a significant shift in the past seven years, evolving from a peripheral presence to one of the most vibrant sectors of the national automotive industry [7,8].

Figure 1 depicts the trends of electric and hybrid vehicle (EV/HEV) imports to Uzbekistan from 2018 to 2024. The figures distinctly illustrate the exponential character of market expansion over this period. Between 2018 and 2020, imports were minimal, with at 13 units in 2018, 39 in 2019, and 131 in 2020. The sluggish adoption rate indicates a lack of specific incentives and insufficient customer awareness in the initial phase of electric vehicle integration [9].

A significant change commenced in 2021, with imports escalating to 809 units, succeeded by a more pronounced surge in 2022 to 2,180 units. This expansion is directly linked to the implementation of governmental support initiatives, including customs duty and tax concessions, which have rendered electric vehicle ownership financially appealing relative to traditional automobiles.

The most significant increase transpired in 2023 and 2024. In 2023, imports surged to 28,384 units, signifying a rise over 13 times that of 2022. The rising trend persisted into 2024, with imports totaling 41,575 units, positioning Uzbekistan as one of the most rapidly expanding EV markets in Central Asia.

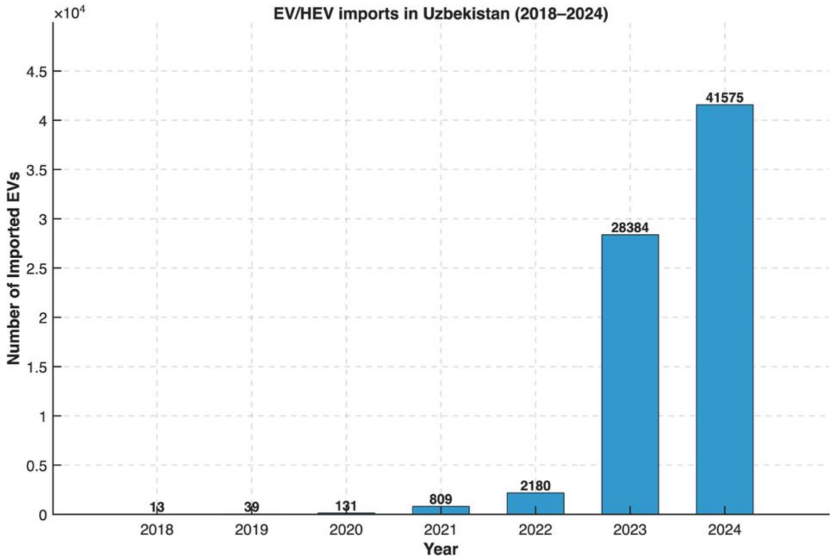

Figure 1. EV/HEV imports in Uzbekistan over 2018-2024

Figure 2 depicts the distribution of electric and hybrid electric vehicles (EV/HEV) throughout the regions of Uzbekistan as of July 1, 2025, represented as a Pareto chart. The histogram bars represent the total number of imported EV/HEV units in each administrative region, whilst the cumulative line illustrates the overall percentage share in relation to the national total.

The data unequivocally illustrates the concentration of EV/HEV in Tashkent city, which comprises 55,826 units, representing over four-fifths of the national inventory. The Tashkent region has 5,262 units, although other regions like Samarkand (2,075 units), Khorezm (1,659 units), and Kashkadarya (1,519 units) have somewhat lesser contributions. The remaining provinces demonstrate relatively moderate adoption, with values ranging from about 1,500 units to fewer than 500 units, and Surkhandarya displaying the lowest share at 203 units.

The cumulative curve underscores the significant spatial disparity: the two leading regions (Tashkent city and Tashkent region) comprise roughly 90% of all EV/HEV in the nation. This trend illustrates the cumulative impact of population density, purchasing power, charging infrastructure accessibility, and governmental incentives, which are unevenly distributed in the capital and its vicinity [9].

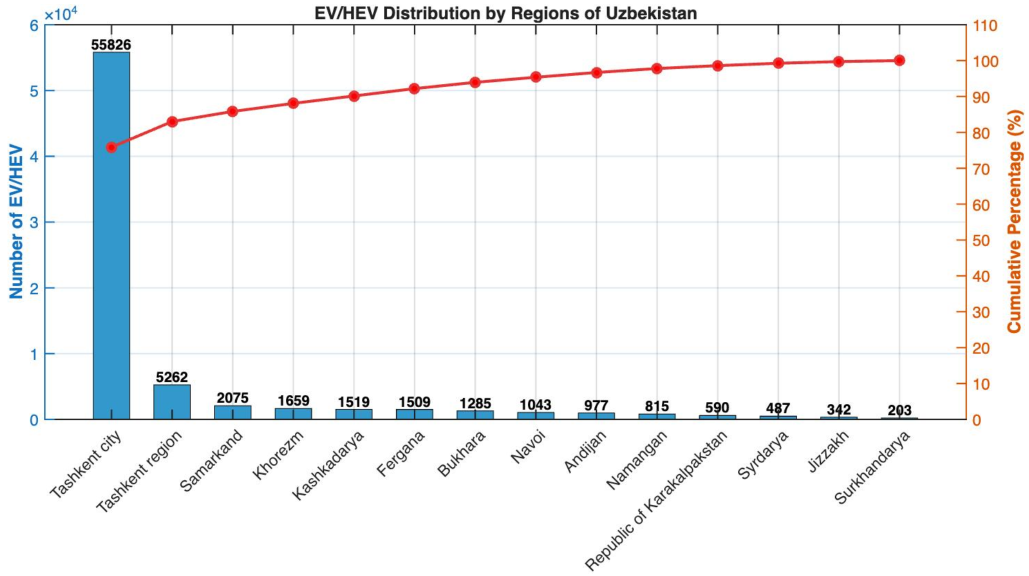

Figure 2. Distribution of EV/HEV by regions in Uzbekistan (as of July 1st, 2025)

Figure 3 illustrates the distribution of passenger automobile sales produced in Uzbekistan by manufacturer for the year 2024, categorized by manufacturer [10]. UzAuto Motors dominates the market, with around 87.9% of total car sales. Other conventional internal combustion vehicle manufacturers, such ADM Jizzakh (7.5%), Jizzakh Auto, SamAuto, and Asaka Motors, collectively account for less than 1% of the overall market.

In contrast, the BYD Uzbekistan Factory, dedicated to electric vehicle (EV) manufacturing, accounted for 4.3% of the nation's production (17,303 units). Although significantly smaller than UzAuto's traditional automobile production, BYD already exceeds the combined output of several major local manufacturers. This highlights the increasing importance of electric vehicle manufacturing in Uzbekistan's domestic automotive sector, despite the continued predominance of internal combustion vehicle production.

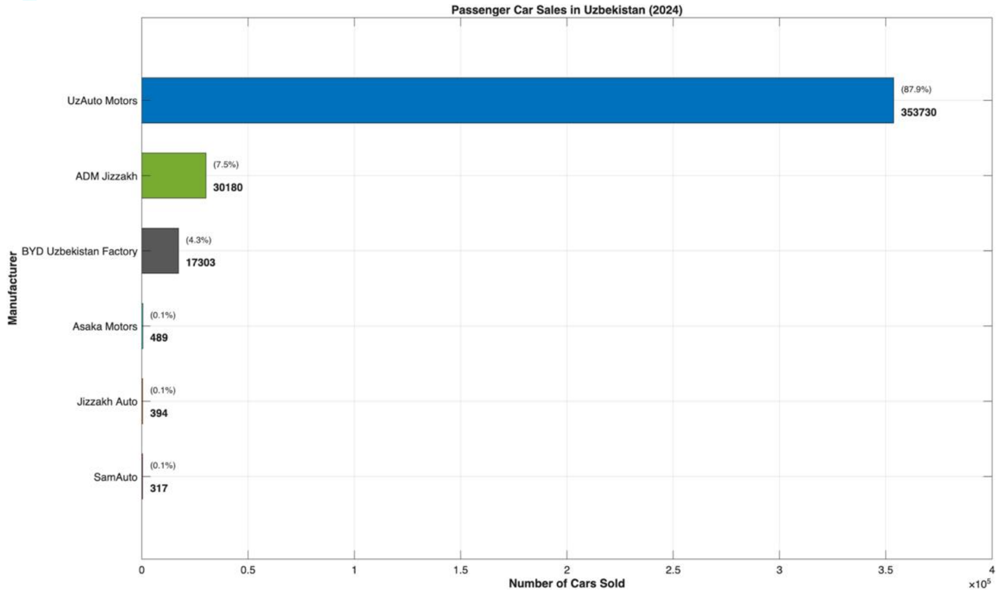

Figure 3. Car Sales in Uzbekistan in 2024

Figure 4 depicts the sales distribution of prominent car models in Uzbekistan for the year 2024. The market is predominantly controlled by locally manufactured Chevrolet models, specifically the Cobalt (34.1%) and Onix (28.4%). Nonetheless, the introduction of BYD vehicles—including the Song Plus Champion DM-i (1.7%), Chazor (1.2%), and Song Plus DM-i (0.8%)—is significant.

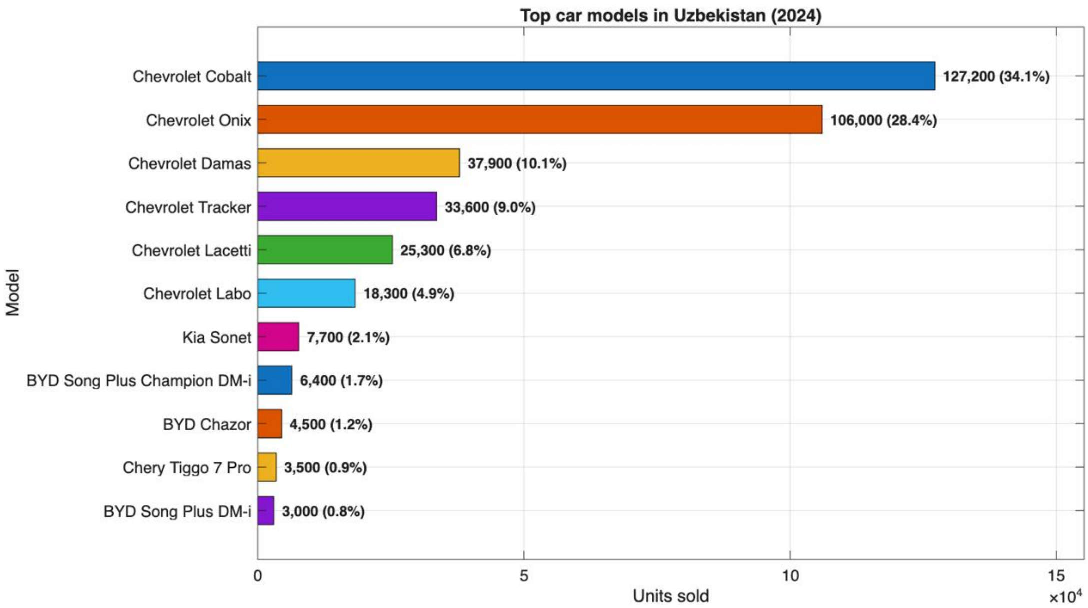

Figure 4. Best-selling car models in Uzbekistan (2024).

Notwithstanding their elevated price relative to traditional competitors, BYD models jointly surpassed 13,000 units sold, indicating a burgeoning market transition towards electrified vehicles. This signifies that the demand for new energy vehicles in Uzbekistan is intensifying, even within a generally price-sensitive sector.

CONCLUSION

The Uzbek electric vehicle (EV) market has grown from low acceptability to one of the fastest-growing areas of the automotive industry in the previous seven years. Government incentives such waivers on customs charges, excise taxes, and VAT reduced ownership costs and increased consumer demand, resulting in a considerable increase in EV/HEV imports, especially after 2021. The BYD–UzAuto joint venture and the huge price decrease of imported electric vehicles, primarily influenced by Chinese manufacturers, signal industrial localization and a new chapter in the sector's development.

While progress has been made, structural challenges persist. Over 80% of the national fleet of electric vehicles are in Tashkent, illustrating regional differences in economic levels, infrastructure, and customer awareness. While growing, charging infrastructure outside large cities is inadequate, and the power system needs upgrading to accommodate widespread car electrification. Although significant, domestic electric car production is still limited compared to traditional internal combustion vehicles.

The Uzbek electric car market is reaching a turning point. Uzbekistan may lead Central Asia in electromobility if current growth trends, supported by government measures, infrastructure investment, and local assembly diversification, continue. Realizing this potential requires resolving certification and recycling regulatory issues, ensuring equal regional charging infrastructure distribution, and building consumer trust through education and aftersales assistance.

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Methods for Emission Reduction in Motor Vehicle

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Abstract. This article provides an overview of the environmental impact of the vehicle and tasks to reduce GHG. 4-step methods of reducing the environmental impact of the vehicle are reflected in the article. The operating modes of the engine in terms of fuel economy and reduction of environmental damage are given in the example of 3 cars. Stated that when power usage grade is U = 0.8 and engine operates in 70-80% of its maximum engine speed a fuel consumption and environmental damage is reduced. The article summarizes the following: operation of the engine with power usage grade around 0.8 in the city conditions can be provided by using engines with appropriate power i.e. a car with big engine power is not necessary in the city conditions in terms of fuel economy and environment protection.

INTRODUCTION

Environment protection is the one of critical human problems, since its solution depends on people life, their health and welfare. Automobile transport is the one of main polluters of an environment. The harmful gas elements are exhausted to atmosphere in the process of the engine operation; five kinds of them are more harmful for human health (carbon dioxide, particle matters, carbon monoxide, hydrocarbon, nitrogen oxide). Nowadays vehicles, which are under exploitation, pollute the atmosphere very much, for instance: if one vehicle consumes 10-12-liter gasoline it exhausts 25 kg different harmful chemical compounds, therefore one vehicle consumes about 4 tons oxygen per year [2]. Exhaust gases of the engine comprise more than 500 harmful organic compounds. Importance of the problem is more critical in the city, where a density of the automobile is high. However, the carried-out measures encourage decreasing the ecological threat. For instance, using daily data collected from more than 200 monitors across the country from 2013 till

2017, they detected, that the quality of the atmosphere has been improved from 21 to 42 % in populated areas of China [11]. Therefore, a lot of them overcome aims, declared in their National program for environment protection.

In 2017, Uzbekistan signed the Paris Agreement, which will improve the environmental situation through activities to reduce emissions, and through modernization and measures to increase energy efficiency. Government of Uzbekistan asks automotive engineers to make a contribution in reducing emissions going from automobile transport. The emission volume is dependent mainly on driving cycle in the real conditions of use.

Keeping global warming at 1,5 ^{0}C requires rapid and long-term transforming processes belonged to earth, power, industrial systems, as well as buildings, transportation, and cities. Mass emissions of carbon dioxide (CO_2) due to human activities will need to be reduced by about 45% by 2030 compared to 2010. By 2050, it is expected to fall to zero [1].

Some facts regarding the harm of the vehicle to environment are given in the table below [2].

Table 1. Volume of GHG in the world emitted from road transport per year

Parameter	Volume
World car fleet	1 000 000 000
Average distance in kilometer covered by a car per year	10 000
Average CO_2 emission in gram per kilometer	100
Total mass of CO_2 in gram	1 000 000 000 000 000
Volume of CO_2 in cubic meter	509 090 909 090
Surface of the earth in square meter	314 160 000 000 000
Thickness of CO_2 in millimeter, which covered the earth	1.62

METHODS FOR EMISSION REDUCTION

The source of environmental pollution when using motor vehicles is often gasoline or diesel fuel. Toxic gases are released from the engine into the environment as a result of combustion of fuel mixed with air inside the cylinder. The process of reducing fuel damage to the environment can be divided into 3 stages. The first is to improve the environment before refueling, i.e. to reduce its damage by changing the composition of the fuel (Euro-5, Euro-6 and etc.).

Phase 2 of the fuel environmental reduction process is to improve the combustion process by influencing the gas distribution phases by controlling the combustion mixture formation in the cylinder, controlling the spark plug ignition timing and changing the valve opening time, and thus reducing exhaust gas damage (Figure 1) [16].

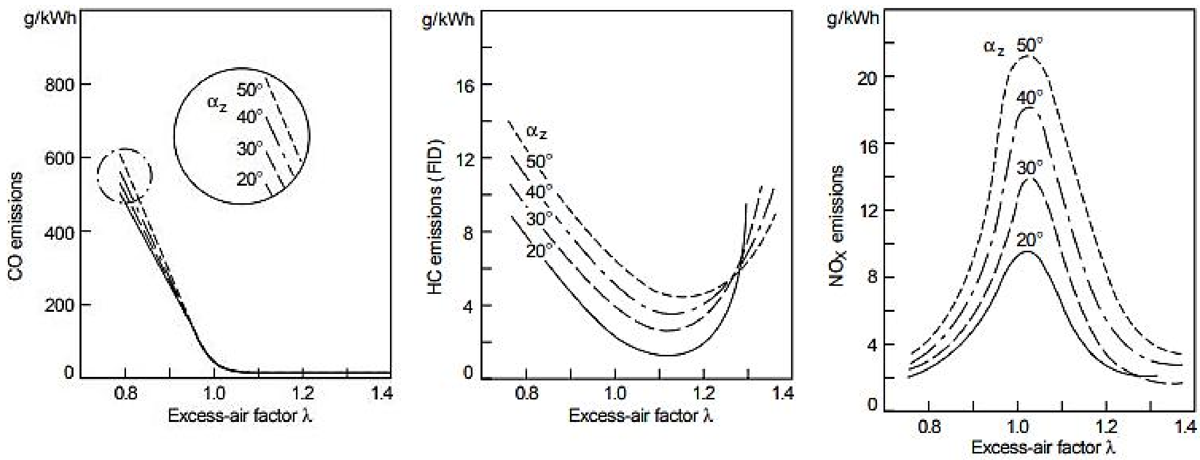

Figure 1. Influence of carbon monoxide CO, hydrocarbon CH and nitrogen oxide NOx to air to fuel ratio and ignition timing advance angle α_z

Studies show that when air fuel ratio is close to 1 or fuel-air mixture is a stoichiometric it provides reduction of carbon monoxide CO, hydrocarbon CH and nitrogen oxide NOx at the same time (Figure 2) [3].

Fuel injection systems with electronic control module (ECM) mounted in modern vehicles provide a stoichiometric fuel-air mixture at engine operation process. In order to prepare a stoichiometric fuel-air mixture ECM receives required signals provided by sensors. One of the main sensors is lambda sensor mounted in the exhaust pipe line and which counts amount of the oxygen concentration in exhaust gas.

Step 3 of the process to reduce the environmental damage of fuel is to filter and neutralize these exhaust gases by three-way catalyst before releasing them into the atmosphere.

The goal of the three-way catalyst is to activate suitable chemical reactions able to reduce simultaneously the concentration of CO, hydrocarbons and NO*x*. Three-way catalysts, so called because of the three regulated pollutants, are also efficient on a number of unregulated chemicals, like polynuclear hydrocarbons, aldehydes and benzene.

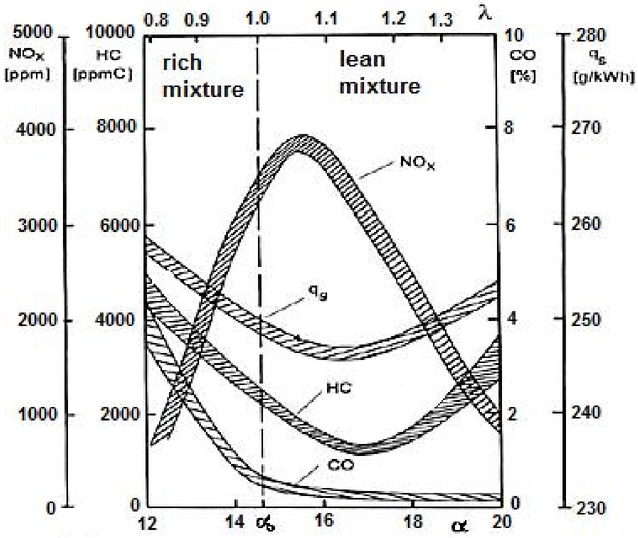

Figure 2. CO, HC, NOx concentrations and specific fuel consumption q_s versus air/fuel ratio α or excess-air factor λ

Ensuring a car's economical driving mode is an effective way to reduce exhaust fumes. The less fuel is used, the less pollution of the environment.

It is known that fuel consumption of the engine in the first approximation can by defined depending on angle velocity of the crankshaft and the power usage grade of the engine [8-10]:

$$G_T = \frac{N_\kappa g_{eN} K_U K_\omega}{1000\eta_{Tr}}, \quad (1)$$

$$K_\omega = a_\omega + b_\omega \bar{\omega}_e + c_\omega \bar{\omega}_e^2, \quad (2)$$

$$K_U = a_U + b_U U + c_U U^2, \quad (3)$$

Here, N_κ - the power on drive wheels of the vehicle, kWt; K_ω, K_U - coefficients that define the relationship $g_e = f(\overline{\omega}_e, U)$ - specific fuel consumption of the engine;

$\overline{\omega}_e = \omega_e / \omega_N$ - engine speed usage factor; ω_e – current angle velocity of the crankshaft (1/s), ω_N - angle velocity of the crankshaft in maximum power.

$U = N_\kappa / N_e \eta_{Tr}$ - Power usage grade of the engine at current angle velocity of the crankshaft by part from the one.

With the help of expressions for coefficients K_ω and K_U the next operating mode of the engine with minimum specific fuel consumption is can be determined by differentiate of the coefficients by $\overline{\omega}_e$, U and researching the extremes.

$$\frac{dK_\omega}{d\overline{\omega}_e} = b_\omega + 2c_\omega \overline{\omega}_e = 0, \tag{4}$$

$$\frac{dK_U}{dU} = b_U + 2c_U U = 0. \tag{5}$$

Relations between coefficients K_ω , K_U and U is shown in the following figure [9].

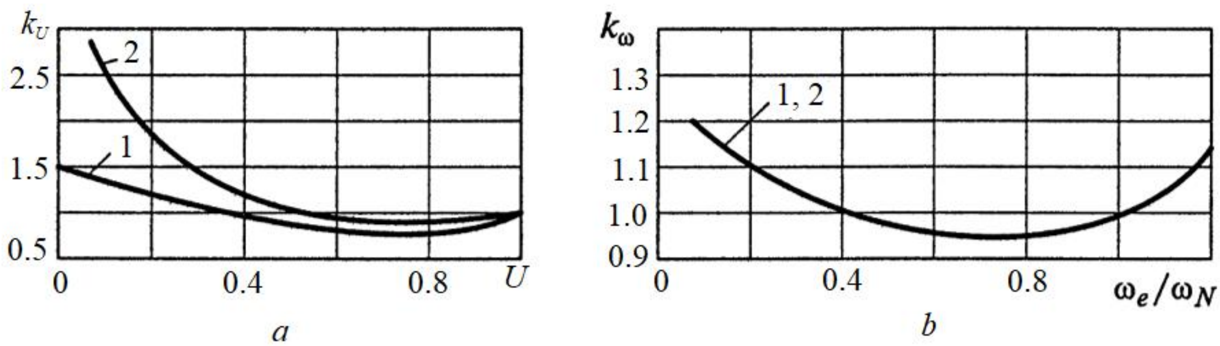

Figure 3. K_U, K_ω coefficients versus factors U and ω_e / ω_N. 1-diesel engine, 2-gasoline engine.

As shown in the picture when the power usage grade of the engine is about 8.0 (Fig. 3 a), we can see minimal values of K_U and when engine operates in 70-80 % of its maximum speed (Fig. 3 b) values of K_ω are less. Therefore, according to formula (1) fuel consumption reduces in this area.

Trucks with gross weight of 40 t and different engines are taken as objects of research, which are indicated as objects A, B, C in the following text.

RESULTS AND DISCUSSIONS

Points *A, B* and *C* in Fig. 4 show operation modes of engines. According to design researches the engine operating *C* does not correspond to minimal fuel consumption area and characterizes by big engine speed (see points in Fig. 4). That is why the object has big fuel consumption than others. Engine *C* uses 50 % of its maximum power and its usage grade is *U = 0,50*. The operation area of the engine *B* does not meet minimal fuel consumption area and engine *B* uses 50 % of its maximum power and its usage grade is *U = 0,50* too. The engine *A* runs in minimal fuel consumption area and engine *A* uses more than 80 % of its maximum power and usage grade is *U = 0,80.* The engine of the object *A* is operating in mode that provides minimal fuel consumption and high specific efficiency (see Fig. 3).

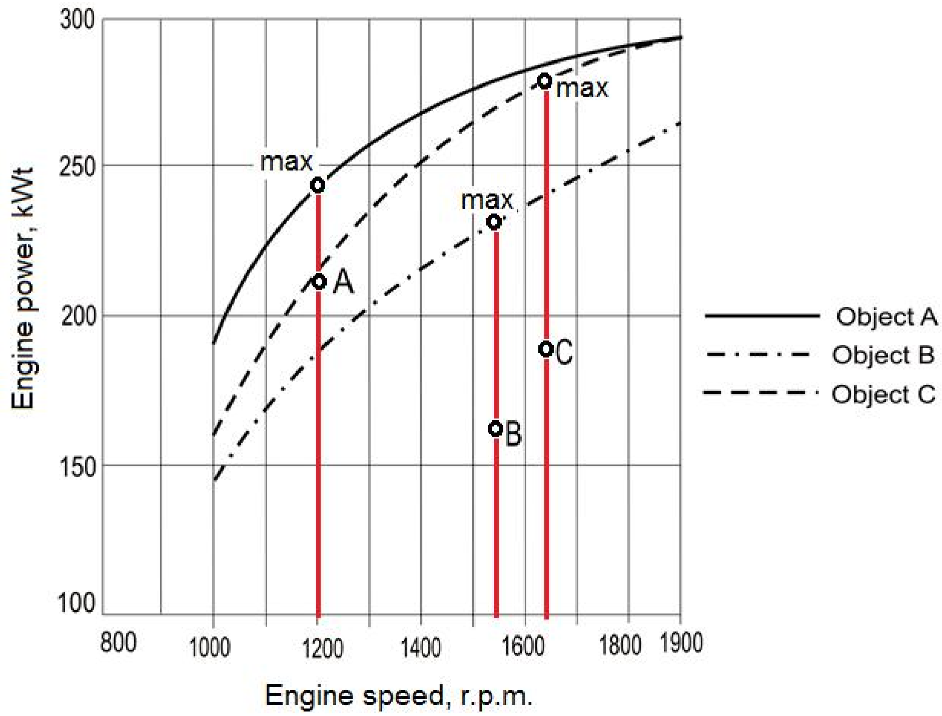

Figure 4. Engine operating modes of the objects A, B, C

CONCLUSIONS

Depending on vehicle ride regime points *A, B, C* in Fig. 4. Can change their position to area with minimum fuel consumption as well as to area with maximum fuel consumption. How less fuel consumption so less pollution of an environment. Operation of the engine with power usage grade around 0.8 often met on high ways.

Operation of the engine with power usage grade around 0.8 in the city conditions can be provided by using engines with appropriate power i.e. a car with big engine power is not profitable in the city conditions in terms of fuel economy and environment protection.

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Analysis of the method for determining exhaust gases in the engine idle mode

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ABSTRACT

During operation, automobile internal combustion engines emit various harmful gases into the atmosphere as a result of complete or partial combustion of the air-fuel mixture. The combustion products mainly include carbon monoxide (CO), unburned hydrocarbons (CH), nitrogen oxides (NO_x) and carbon dioxide (CO_2), the concentration of which directly depends on the composition of the mixture, combustion conditions and technical condition of the engine. Due to their negative impact on human health and the environment, these gases have been accepted as the main criterion for assessing the environmental safety of automobiles, and over the past 60 years, the environmental safety requirements for automobiles have been consistently developing. Initially, the emphasis was on limiting CO, CH and NO_x

emissions, but in subsequent stages, reducing CO_2 emissions and increasing fuel efficiency became a priority. In this process, testing methods from Euro-1 to Euro-6, as well as WLTP and RDE were put into practice. As a result, automobile manufacturers, by introducing new technologies - catalytic converters, electronic fuel injection systems, lambda probes, modern combustion control algorithms, evaluate the achievements of the design in terms of environmental friendliness according to the above requirements. However, the detection of exhaust gases under various operating conditions requires large financial costs, a lot of time and significant labor resources. It is urgent to develop a new method for detecting automobile exhaust gases under operating conditions. In this article, taking into account the operating characteristics of a stationary gas analyzer, a car engine was tested in stationary conditions, with the gearbox disconnected. The experiments were carried out at low and medium engine crankshaft speeds in the range of 750–3000 rpm, and graphs and maps of the composition of exhaust gases were developed. During the study, the concentrations of four main components - CO, CH, NO_x and CO_2 were determined.

Keywords: exhaust gases, CO, CH, NO_x, CO_2, test method, fuel consumption, air consumption, conventional operating mode.

INTRODUCTION

Various testing and calculation methods are used to determine harmful gases emitted by motor vehicles. These testing methods are based on several scientific and technical approaches [1]. For example, engine dynamometer tests are widely used in the in-depth experimental study of automobile engines, optimization and tuning of their operating parameters [2,3,4]. In the complex assessment of vehicle emissions, chassis dynamometer tests are one of the most important laboratory tools, which allow the entire engine-transmission system of the vehicle to be analyzed as a whole and allow modeling of various loading and driving modes. However, this method cannot fully reflect real operating conditions [5,6,7]. Therefore, since 2011, PEMS (Portable Emission Measurement System) technology has been introduced into practice, which allows for real-time measurement of exhaust gases in vehicles that meet the requirements of EURO-5. PEMS equipment can measure CO, NO, HC, CO_2, and PM emissions [8,9]. Scientific studies have shown that PEMS results are more accurate and reliable than dynamometer measurements in tests conducted under identical conditions [10,11,12]. However, the use of these test methods requires a lot of time and material resources to assess the environmental performance of vehicles in operation. In addition, these methods are also widely used in the final stages of vehicle production to calibrate electronic control unit (ECU) parameters and assess design development. In many developed countries, exhaust emissions from vehicles in operation are measured in real time and during movement using remote sensing technology [13]. The main advantage of this method is that it allows for the assessment of a large number of vehicles in a short time, remotely. This allows for quick and accurate adoption of socially and environmentally important solutions.

Current methods and standards for determining exhaust gases from vehicles in operation do not sufficiently cover the capabilities of the improved design of modern vehicles. According to the test method, the composition of exhaust gases is measured in stationary mode, at a certain engine speed and without load. This does not allow for an accurate assessment of the amount of harmful gases produced in real operating conditions (city traffic jams, mountainous or uneven roads, frequent changes in speed). In addition, only CO and CH gas indicators are assessed on demand. This does not provide a sufficient assessment of the environmental characteristics of the vehicle in terms of exhaust gases.

METHODOLOGY

Determining the composition of exhaust gases from in-service vehicles is one of the most pressing environmental issues. Therefore, a methodology has been developed to determine the amount of exhaust gases from in-service gasoline-powered vehicles, based on the technical characteristics of the existing technical base, the level of sensitivity, and the scope of application.

The object of the study was a passenger car - Chevrolet Cobalt. The main technical parameters of this vehicle are given in Table 1. During the experiment, stable normal operation of the engine was ensured without additional loads.

Table 1- Main technical parameters of the Chevrolet Cobalt

№	Indicators	Name/Value
1	Year of manufacture of the car	2022
2	Engine type	Gasoline
3	Gasoline	AI – 92
4	Engine displacement, cm^3	1485
5	Power, kW (hp)	78(106)
6	Torque, Nm	141
7	Gearbox type	Automatic transmission
8	EURO standard	EURO - 4

The experimental work was carried out in laboratory conditions. The car was started in a stationary state, and the engine was operated in the normal operating mode, with the crankshaft rotation frequency maintained in the range of 750 - 3000 rpm. Measurements were made four times at each value - 750, 1000, 1500, 2000, 2500 and 3000 rpm. The average values of the results are given in Table 2.

Table 2- Average values of the results obtained in the gas analyzer

№	Frequency of rotation of the engine, rpm	CO, %	CH, mln-1	CO2, %	NOx, mln-1	λ
1	748	0,33	188	13,9	0,68	1,02
2	1000	0,26	91	14,08	0,94	1,04
3	1500	0,19	59,4	13,94	0,67	1,03
4	2000	0,08	68,8	14,29	0,54	1,027
5	2500	0,08	33,2	14,32	0,44	1,02
6	3000	0,07	23,61	14,52	0,43	1,02

During the measurement, the sensor tip of the gas analyzer was placed in the exhaust pipe at the rear of the vehicle. First, the engine was kept stable for 20 seconds at a normal operating speed of 750 rpm. Then the sensor was placed in the exhaust pipe and the measurement was carried out for 30 seconds. Later, the sensor was removed, since it was necessary to purge the old gases from the internal chamber of the gas analyzer for subsequent measurements. In this way, four measurements were taken at each engine speed.

Test process Engine operating parameters were synchronously recorded in computer memory by means of Scanmatic diagnostic equipment. The connection sequence of the devices is shown in Fig. 1.

Figure 1. Connection of devices. 1 – scanmatic, 2 – computer, 3 – car, 4 – gas analyzer, 5 – place of connecting cable of scanmatic.

In order to ensure data exchange with the vehicle's ECU, the main cable of the Scanmatic diagnostic device was connected to the ECU connector of the vehicle. The second interface cable of the device was connected to a personal computer, which required the special Scanmatic software to be pre-installed on it. At the same time, the gas analyzer used to determine the composition of the exhaust gases was connected to the power supply via the 12 V battery of the vehicle and brought into operation. During the study, both measuring instruments (diagnostic scanner and gas analyzer) were brought into a synchronous state in the same operating mode.

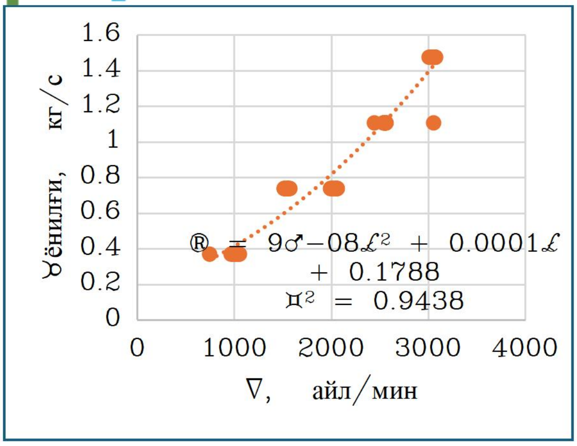

Figure 2. The graph of the dependence of the number of revolutions of the engine crankshaft and fuel consumption.

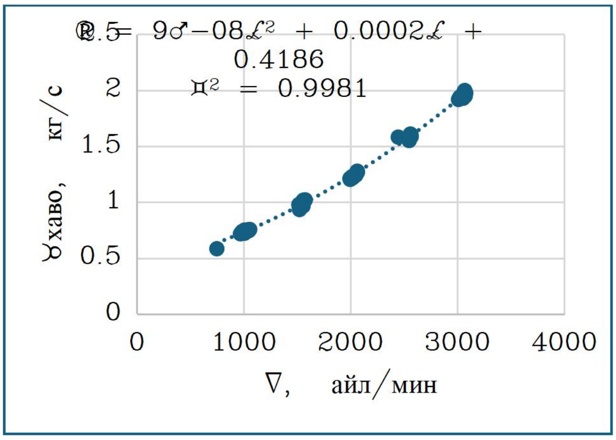

Figure 3. The graph of the dependence of the number of revolutions of the engine crankshaft and air consumption.

Based on the experimental results obtained, the equations of the graphical expressions and their approximation values were determined. In this process, the functional relationships between the number of engine crankshaft revolutions and air consumption, fuel consumption, and the total mass of exhaust gases were mathematically analyzed. Figure 2 shows a graph of the correlation between fuel consumption and the number of engine crankshaft revolutions.

Analysis of the results presented in Figures 2–3 shows that with an increase in the number of engine crankshaft revolutions, fuel consumption and air intake increase proportionally. The main reason for this is that the ECM ensures that the fuel-air mixture is maintained in an optimal state. In particular, the λ coefficient is constantly controlled and, under ideal conditions, is equal to the value $\lambda = 1$, which represents a stoichiometric mixture. In the stoichiometric state, the fuel and air ratio is sufficient for complete combustion, as a result of which the harmful substances in the exhaust gases are reduced to a minimum and the engine efficiency is ensured at a high level. Figure 4 shows a comparative graph of CO and CH gases determined experimentally with the requirements of GOST 12.2.2.03-87.

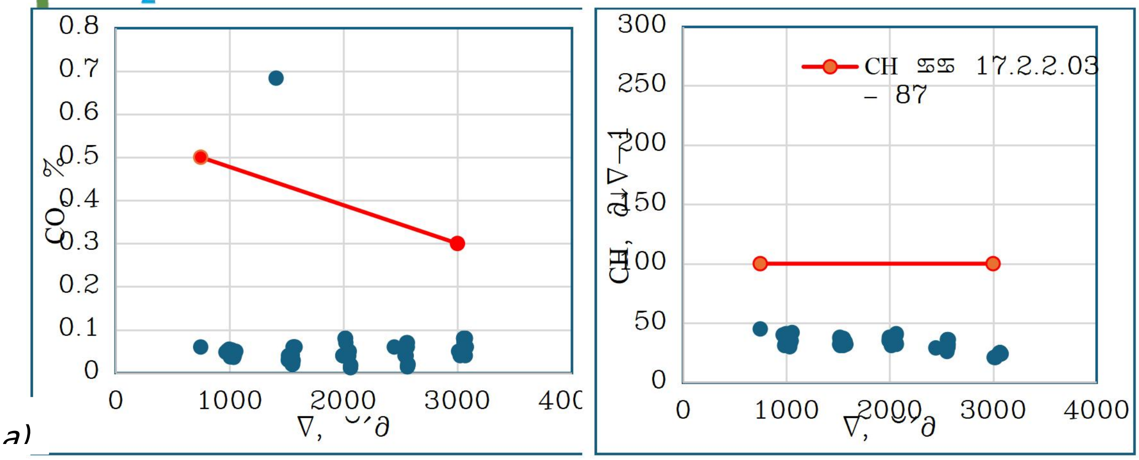

Figure 4 – Comparison graph of experimentally determined CO and CH gases with the requirements of GOST 12.2.2.03-87 standards

The results of the comparative analysis of the test results with the current standard requirements show that the concentration of the two main harmful components in the exhaust gases - CO and CH - did not exceed the established regulatory indicators, but were recorded at a very low level. This situation, on the one hand, is explained by the high level of compliance of modern cars in operation with practical environmental requirements, and on the other hand, it clearly demonstrates the stage of their constructive and technological development.

CONCLUSION

It is based upon the findings of the test that the observation of substantially reduced emissions necessitates a further consideration of the scales of accuracy and precision of the current methods of gauging and estimating vehicle emissions and that circumstance implies the necessity of creating high-precision, novel methods of measuring and estimating vehicle emissions. Thus, the implementation of modern testing technologies and techniques, additional enhancement of the environmental monitoring system, and its greater credibility are of strategic significance to environmental protection and the world environmental stability.

ACKNOWLEDGEMENT

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Calculation method for gasoline engine exhaust gas emission prediction

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ABSTRACT

Increasing the emission performance of vehicles is an urgent task of every manufacturer. These indicators of new cars are achieved by adjusting the electronic control unit to the required level. However, it is an urgent issue to evaluate the compliance of the amount of exhaust gases of cars in use with the regulatory requirements. There are steady-state norms for them. The detection of exhaust gases in the process of driving a car has not found a modern solution. Current calculation methods determine the average of 1 kg of fuel and gases released from it. As a result, an average calculation for determining the daily and annual amount of gases was developed. However, it is the method of calculation in the process of movement that is considered relevant. The article is devoted to the development of a calculation method for the determination of CO, CH, NOx in exhaust gas depending on the oxygen-fuel mixture.

Keywords: carbon monoxide (CO), hydrocarbons (CH), nitrogen oxide (NOx), air excess coefficient (α), exhaust gas diagram.

INTRODUCTION

There are control problems due to the narrowness of the test method for determining the composition of vehicle exhaust gases in operational conditions, and the test methods for stationary mode without movement. Therefore, an attempt was made to create a method for determining the composition of car exhaust gases based on the data obtained from the electronic control unit (ECU) of the engine. The automobile industry is developing rapidly. The increase in the number of vehicles leads to an increase in harmful gases released into the atmosphere. In our country, many practical works are being carried out to improve such an ecological situation. In an article by B. A. D'Alleva and W. G. Lovell, full exhaust gas analyzes for carbon dioxide, carbon monoxide, hydrogen, methane, and oxygen were performed directly measuring air-fuel ratios for three engines with different operating conditions and different air metering devices[6]. Several such scientific sources were analyzed[7, 8, 9, 10]. European countries are engaged in a lot of scientific research in this field. In particular, Justin D.K. Bishop and others have worked on the fuel consumption and the amount of exhaust gases in the vehicle driving cycle per unit time [1]. B.I. Bazarov gave a method of calculating the mass of harmful substances. Methods for calculating the mass (daily or annual) of emissions of harmful substances into the atmosphere of a certain type of vehicle are given [2,P.110]-

In their study, Hata Hiroo et al. measured the exhaust gases of gasoline engines running after different idling times using a chassis dynamometer[3]. Scientific research works were carried out by experts in our country. Conducted research on the use of gasoline-hydrogen fuel to minimize carbon emissions from exhaust gases of automobile engines.[11] In particular, special programs were used to calculate emissions at the intersection [4], and the main parameters of the engine in the motion cycle were calculated [5]. Meeting the environmental class of the car has become a strict criterion for every vehicle. Many scientific research activities of experts in the field of reducing automobile exhaust gases have been put into practice and are yielding results.

METHODOLOGY

The purpose of our study is to create a calculation method based on the available EDB data. The following parameters of the passenger car engine were obtained through laboratory tests: engine crankshaft rotation frequency, throttle valve opening degree in 4 cases 25-50-75-100%, air-fuel ratio. The volume of exhaust gases emitted from the engine, i.e. CO, CH, NOx, was calculated and compared. A graph of the dependence of exhaust gases on the fuel-air mixture was used (Fig. 1). The results of the test process are shown in Table 1.

Table 1-Car engine test results

Car engine test results

№	**E Speed rpm**	**T Pos %**	**AFR**	**T Pos %**	**AFR**	**T Pos %**	**AFR**	**T Pos %**	**AFR**
1.	1000	25	14,7	50	14,3	75	12,8	100	13
2.	1400	25	14,9	50	15,1	75	13,8	100	13,5
3.	1800	25	15,2	50	14,8	75	14	100	13,4
4.	2200	25	14,7	50	14,6	75	13,5	100	13
5.	2600	25	14,8	50	14,9	75	13,7	100	13,4
6.	3000	25	14,8	50	14,4	75	14	100	13,5
7.	3400	25	15,1	50	14,9	75	14,1	100	13,8
8.	3800	25	15,3	50	14,7	75	13,9	100	13,5
9.	4200	25	15,5	50	14,7	75	13,3	100	13,2
10.	4600	25	15,4	50	14,7	75	13,2	100	13,3
11.	5000	25	15,4	50	14,6	75	13,3	100	13,3
12.	5400	25	15,1	50	14,4	75	13,3	100	13,3
13.	5800	25	15,2	50	14,2	75	13,3	100	13,4
14.	6200	25	14,5	50	14,5	75	12,8	100	12,7

The terms in the table are as follows: *E Speed, rpm* - engine shaft speed, min^{-1}; *T Pos*, % - throttle opening position degree; *AFR* - air/fuel ratio;

Figure 1 below shows the graph of exhaust gases as a function of α, and the amount of exhaust gases in 4 different positions of the throttle valve is shown by color. Through the air-fuel ratio (AFR), the excess air coefficient is calculated and plotted. Through the graph, it is possible to study the performance level of EBB at 25% α=0.98-1.05 and 50% α=0.94-1.01 values of *T Pos*.

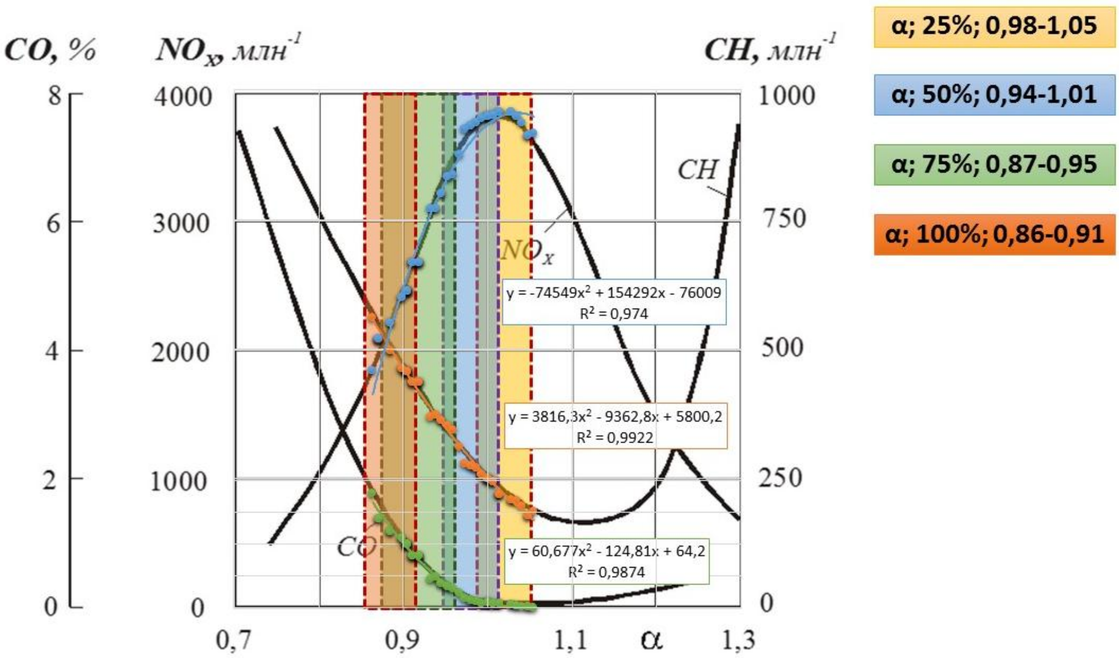


Figure 1. Dependence of harmful exhaust gases on the air-fuel mixture.

An indicator of equality α=1 is required for the reliable operation of the optional internal combustion engine. The calculation of this indicator is not given in the ECU indicators, but it is taken into account in the internal written program. The graph is approximated and the function equations are calculated.

We connected the results obtained from the experimental work with the engine crankshaft rotation frequency to justify its reliability (Fig. 2). The relationship between a and E Speed, rpm is given in many scientific studies.

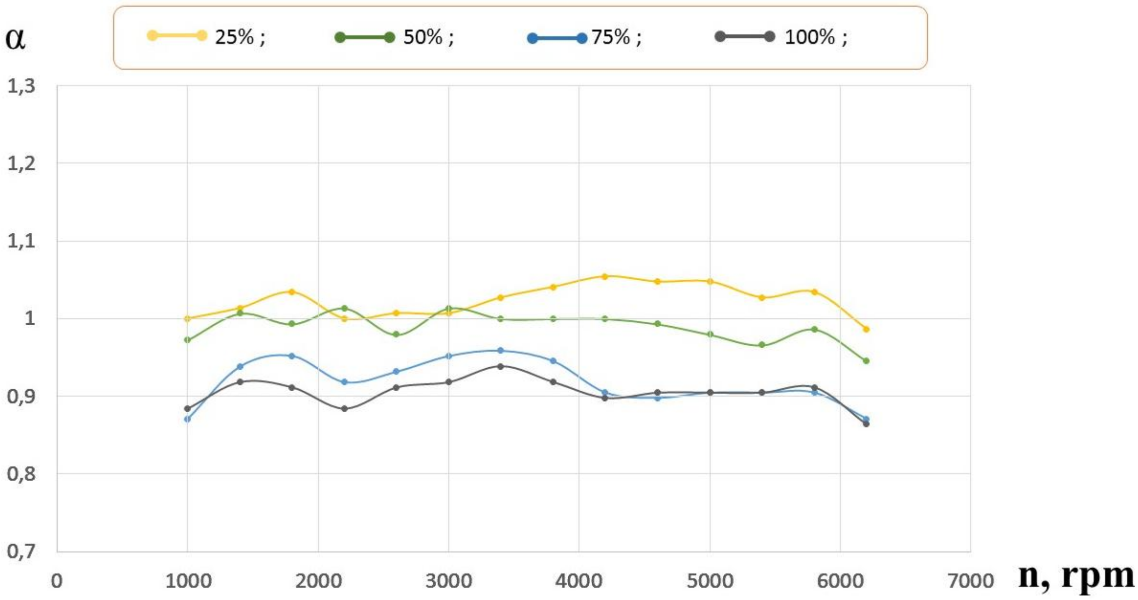
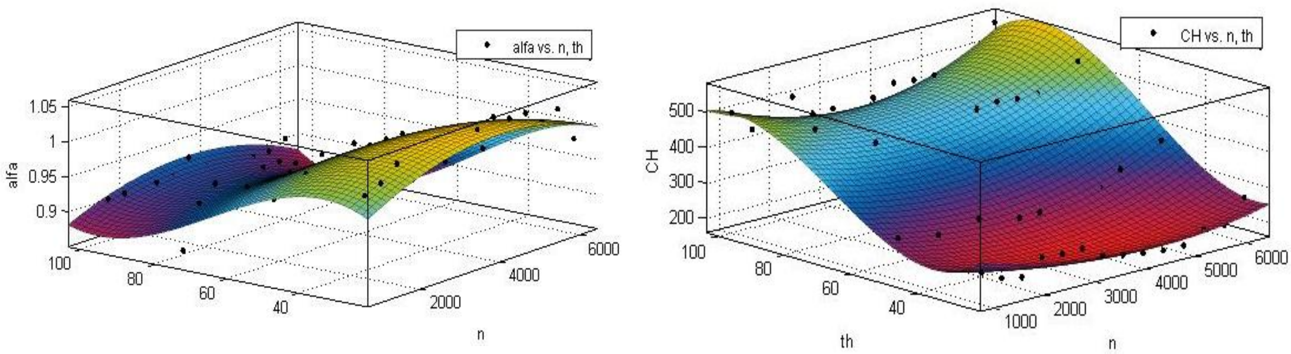


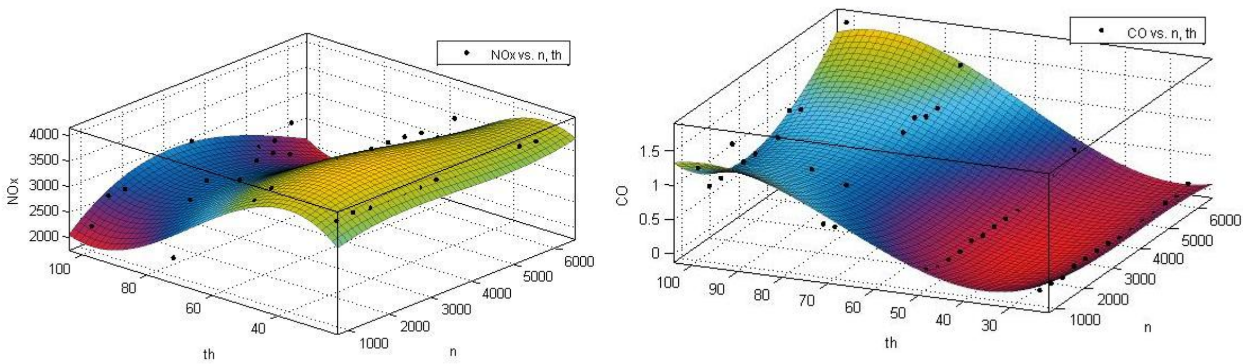
Figure 2. Graph of the dependence of the value of α on the crankshaft rotation frequency for four degrees of throttle valve opening.

The obtained results were calculated in the MatLab R2014a program and displayed graphically. As a result, it becomes the basis for developing a map of waste gases. Today, the modern method of calculation is to generate an emissions card. Below, the graphs of figures 4-5 are expressed on the basis of Table 1, in particular, part "a" of figure 4 is developed based on figure 2 above. Amounts of SO, SN and NOx gases are expressed based on figure 1.



a) **b)**

Figure 4. Dependence graphs. Dependence of a on α, alpha(α), (n) ICE the frequency of crankshaft rotation, th - throttle valve; b – Dependence on CH.



a) **b)**

Figure 5. Dependency graphs. a – Dependence on NOx; б – Dependence on CO.

NOx gas was more emitted, with higher values at 25% and 50% throttle, and lower values at 75% and 100%. EGR system is used in modern engines to reduce the amount of NOx gas. According to experiments, when 5 percent of used gases are re-introduced, the emission of nitrogen oxides is reduced to 40 percent from the initial level, and when 15 percent is re-introduced to 60-70 percent..

CONCLUSION

The exhaust gas output of a car depends on many parameters. The study was carried out when it depends on the amount of exhaust gases based on the indicator of the oxygen-fuel mixture. The calculation method was developed without the use of a gas analyzer. Correlation was analyzed based on generally known patterns.

Mathematical expressions in the determined calculation method had errors R^2 = 0.987 for CO, R^2 = 0.992 for CH, R^2 = 0.974 for NOx (Figure 1). Scientific research work is being carried out on the development of the calculation method for the modes of dynamic movement of the car. Since the dynamic regime is short-term, it is appropriate to use modern tools or formulas based on scientific theory to calculate the amount of exhaust gases.

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Digital method of monitoring vehicle exhaust gases

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ABSTRACT

Exhaust gases emitted by vehicles have a significant negative impact on environmental sustainability and the environment, accounting for a significant share of the total emissions. Therefore, large-scale research and practical measures are being carried out around the world to reduce the negative effects of these emissions and effectively manage them. Along with the gradual tightening of the EURO environmental requirements developed and implemented by the United Nations, test methods used to determine exhaust emissions are constantly being improved, and the technical level of testing equipment is aimed at ensuring high accuracy, speed and reliability. In particular, taking into account the above environmental requirements in the production of cars, the environmental safety of the design is assessed using modern test methods based on international standards, such as dynamometers, PEMS (Portable Emission Measurement System), WLTP (Worldwide Harmonized Light-Duty Vehicles Test Procedure) and RDE (Real Driving Emissions). However, the process of measuring the composition of exhaust gases of operating vehicles is labor-intensive, time-consuming and expensive, which makes it difficult to carry out emission measurements on a large number of vehicles. The development of a digital method for monitoring exhaust gases using data from the electronic control unit (ECU) of operating vehicles is currently relevant. This article proposes a method for determining the amount of CO2 in exhaust gases per unit of mileage by digitalizing the vehicle ECU data.

Keywords: exhaust gases, gasoline engine, EBD, digitization, OBD-II, monitoring

INTRODUCTION

The growing number of vehicles results in a significant increase in the level of environmental impact and pollution [1]. To manage this process, strict environmental requirements, regulations and advanced testing and evaluation methods are being introduced worldwide to reduce harmful emissions from vehicles [2]. In particular, WLTP is a methodology that involves testing vehicles in laboratory conditions on cycles close to real driving conditions, while RDE allows for direct measurements of vehicle exhaust emissions on real roads using PEMS devices [3,4]. The advantage of these approaches is that exhaust emissions are assessed under real driving conditions, which eliminates discrepancies between laboratory results and road conditions and increases the environmental responsibility of manufacturers. At the same time, these tests also have some disadvantages, which are characterized by high cost, duration and complexity of the results processing process. The WLTP and RDE test methodologies are closely linked to the EURO 6 environmental requirements and allow for real-world monitoring of compliance with the strict NOx, CO, HC and PM emission limits set by these standards [5,6,7]. This will improve the practical effectiveness of the EURO 6 standards and strengthen the international environmental policy to reduce emissions from road transport. To meet environmental requirements and reduce harmful emissions, a number of advanced technologies are widely used in modern automotive engineering. For example, turbocharging technology plays an important role in increasing engine power and torque, reducing fuel consumption and reducing CO_2 emissions, ensuring high efficiency of small-displacement engines [8]. However, the complexity of the design of this system and its high production costs, turbo lag and the need for additional care during maintenance are its main disadvantages. Gasoline direct injection (GDI) technology also provides precise control of the air-fuel mixture, increasing engine efficiency, reducing fuel consumption and reducing CO_2 emissions. However, the complexity and cost of the high-pressure system, increased NOx emissions and carbonate deposit formation are some of the disadvantages of this technology [9]. In addition, start-stop systems are also widely used, which automatically start and stop the engine when vehicles are stopped at traffic lights or in traffic jams, providing fuel savings and reducing CO_2 and CO emissions [10]. However, its disadvantages include rapid wear of the starter and battery, reduced efficiency in cold climates and limited practical application for short-distance trips. Three-way catalytic converter technology is capable of simultaneously neutralizing CO, HC and NOx and is one of the main tools for meeting strict environmental standards such as EURO 6 [11]. However, the need to use precious metals such as platinum, palladium and rhodium, poor performance at high temperatures (low cold start efficiency) and decreased efficiency over time are its main limitations. Given the above technological advances and environmental regulation requirements, the development of digital methods for monitoring exhaust gases from vehicles in operation is one of the most pressing areas. This approach not only allows for real-time monitoring of emission processes, but also plays an important role in analyzing the collected data, assessing the level of environmental risk, and ensuring that vehicles comply with international standards. Therefore, the introduction of digital monitoring systems is an important scientific and technical task that ensures the comprehensive development of the automotive industry and the environmental control system.

METHODOLOGY

Conventional driving tests systems, such as the NEDC and WLTC cycles cannot give a full picture of actual driving scenarios, as the driving behavior of the test driver has a profound impact on fuel consumption and emissions. The identification of environmental performance and impact of a car in the actual working conditions is a complicated scientific and technical undertaking. Thus, to identify the environmental performance of the car in the real operating conditions, real driving processes were observed and considered with references to the data received through the different sensors, which are linked to the on-board electronic control system.

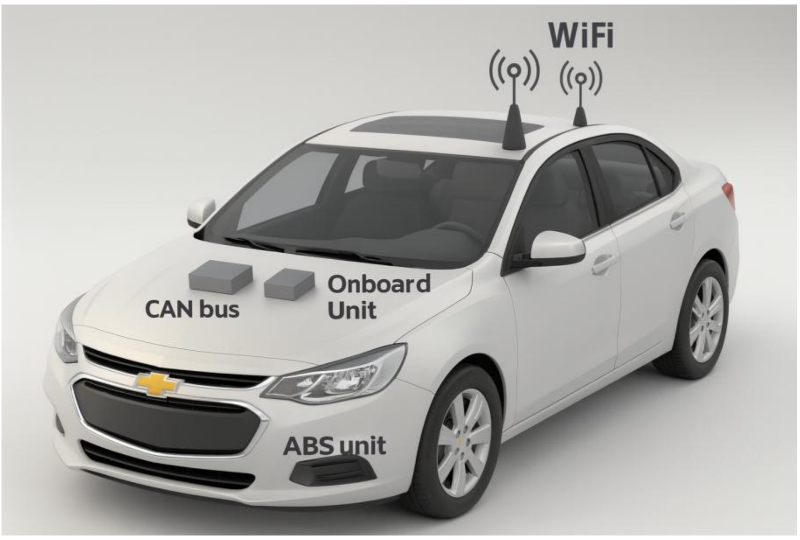

Figure 1. On-board measurement systems

Parameters retrieved through the OBD-II interface are a set of significant indicators directly connected to the car modes of operation and the formation of exhaust gas. These include vehicle speed, indicators determining the stoichiometric air-fuel ratio, intake air mass flow rate, engine speed (rpm), engine load, accelerator pedal position, lambda probe output voltage, fuel injector opening time, and intake air temperature (Figure 1). Systematic monitoring of these parameters and analysis of their interrelations create an important scientific basis for assessing the environmental efficiency of the engine and numerically determining exhaust gas emissions. In the course of experimental studies, a Chevrolet Cobalt was chosen as the test object. This vehicle was chosen for a number of reasons, including the fact that its 1.5-liter gasoline engine has technical characteristics typical of vehicles that are widespread in the region and actively used in practice, as well as the ability to obtain test results that meet environmental requirements and international standards applicable in local conditions. In addition, an important criterion for choosing this model was the ability to reliably record the necessary diagnostic parameters via the OBD-II system of the Chevrolet Cobalt. To determine the composition of exhaust gases, the Infracar gas analyzer was used. The tests were carried out at various constant speeds, given that the gas analyzer operates in a stationary mode.

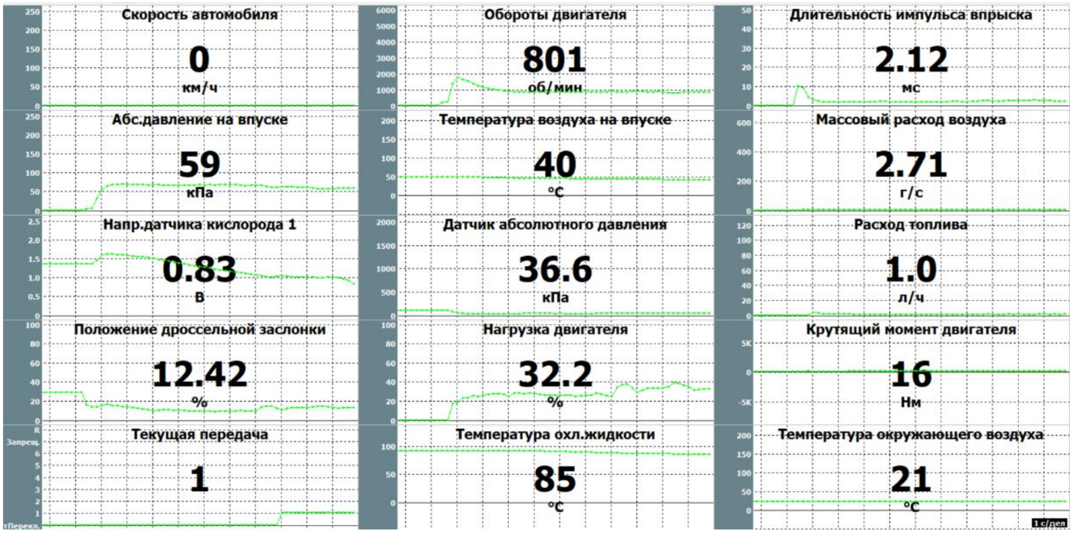

Figure 2. Software interface for collecting vehicle OBD II parameters.

In the process of determining the concentration of CO_2 in the exhaust gases of cars, experimental tests were first carried out, and the volume fraction of CO_2 was recorded in real time using the INFRACAR gas analyzer in various constant speed modes (Fig. 2). At the next stage, the obtained experimental data were processed based on mathematical analysis and the mass amount of CO_2 emission per unit of time was determined. At the same time, based on the parameters obtained through the OBD-II interface, the volume of CO_2 was calculated, and the results were compared with the experimental test indicators. The comparison results showed that the difference between the calculated values end the data recorded using the gas analyzer did not exceed 3-4% (Fig. 3), which confirms the high accuracy and sufficient reliability of the developed calculation method for practical application.

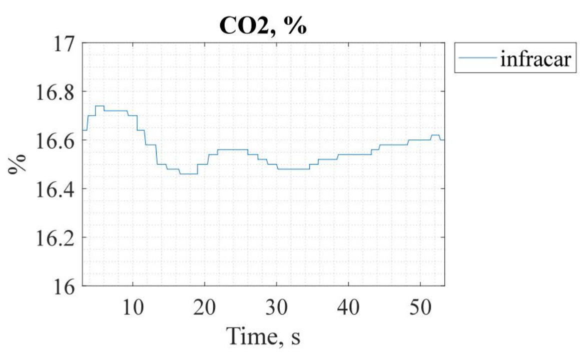

Figure 3 Gas analyzer results

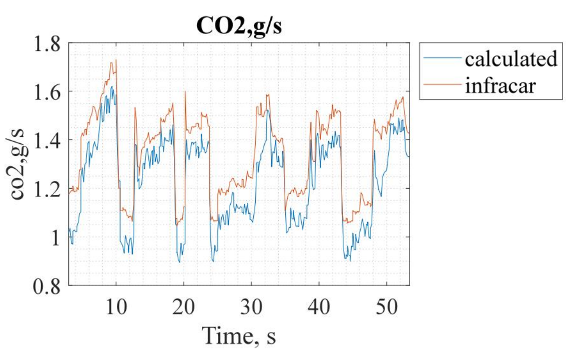

Figure 4 Calculation and test results

CONCLUSION

The experimental tests and mathematical analysis have demonstrated that the difference between the results received in laboratory conditions under the INFRACAR gas analyzer and the calculation method on the basis of the OBD-II parameter is not more than 3-4%. This number proves the great accuracy of the worked-out method of calculation and its practical use. Simultaneously, the digital method has such benefits over experimental measurements as speed, convenience, and cost-effectiveness, which provides sufficient opportunities to enhance efficiency in monitoring the surrounding environment when driving a vehicle. Meanwhile, the obtained results suggest that the calculation algorithms should be improved further, and more tests with different driving conditions and engine load modes should be conducted.

ACKNOWLEDGEMENT

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Safety of the traffic in mountain conditions

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ABSTRACT

Uzbekistan has highways, which pass through mountain conditions. This research is dedicated to solve problems related traffic safety on Kamchik mountain road, which connects Fergana valley with other regions of Uzbekistan. Every day thousands of trucks carry different cargos through this road. This road has big longitudinal slopes and difficulties occur for motion of vehicles. The road is equipped with runaway truck ramp to provide traffic safety. This article presents the results of determining the relations between length of the runaway truck ramp, the speed of the vehicle when entering the runaway truck ramp, the slope of the road, the weight of the vehicle and the type of ramp surface. Mentioned above relations were determined by computational methods. The parameters of the runaway truck ramp are substantiated for different speed modes of vehicles when descending from a mountain. The formula to determine of the length of runaway truck ramp, which includes longitudinal slope of runaway truck ramp, vehicle deceleration, inertia force of the vehicle, air resistance force, vehicle gross weight, rolling resistance force, vehicle instantaneous speed and etc. has been developed. Using this formula, a length of runaway truck ramp has been determined for different speeds of the vehicle at the enter to the ramp. Forces acting on

the vehicle in its movement to the uphill and downhill are shown and analyzed by schemes and diagrams.

Keywords: Runaway truck ramp, Ramp surface, Gravity, Rolling resistance, Vehicle gross weight, Uphill resistance.

INTRODUCTION

Controlling the speed of trucks on continuous slopes is an important indicator. Many road traffic accidents are observed as a result of overspeeding of trucks on long downhill slopes due to gravity or brake system failures. When drivers use the car's service brake many times, the friction between the brake drum and the brake pad decreases as a result of the heating of the brake mechanisms. This causes trucks to go out of control and overspeed. In order to stop a speeding, out-of-control vehicle, it is necessary to define emergency access lanes. An out-of-control car is usually the result of the brakes overheating due to mechanical failure or the driver losing stopping power due to not downshifting in time. Extensive experience in constructing runaway truck ramps (RTR) on existing highways has led to the design and installation of effective RTR that save lives and reduce property damage. In case of an emergency, the distance between the installation of the access road is determined by the forces acting on the vehicle moving on the slope.

MAIN PART

Activities such as the installation of RTR, expansion of the traffic area in parking lots or recreation areas are the most necessary conditions for ensuring safety. If such measures are not provided during the road repair, safety measures should be implemented before the repair. However, the above-mentioned measures cannot exclude the sudden breakdown and stopping of cars on the road. Therefore, it is necessary to develop measures for the evacuation of technically defective vehicles and to determine the distance between the places of installation of special safety lanes and their structural parameters to stop the car even if the brake system does not work, on the road in the dark prevention of dangerous situations is an urgent issue of economic and social importance.

Theoretical and experimental methods of diagramming, mathematical modeling, experimental studies, curve approximation, logarithmic approximation methods, instantaneous speed methods, comparative analyze methods were used in the research process.

The installation distance of RTR is determined as follows, taking into account the operational indicators of vehicles. In this case, the change in the kinetic energy of the vehicle is equal to the work done by the resistance forces acting on it.

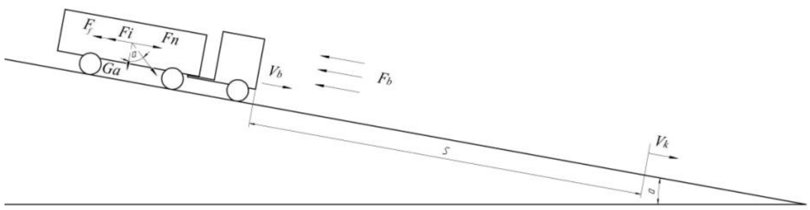


Figure. 1. Forces acting on the car on continuous slopes.

On continuous slopes, vehicles move under the influence of the following forces when the braking system is in a faulty state (equation of resultant driving force):

$$F_h = F_n - F_i - F_f - F_v \quad (1)$$

F_h is the resultant force driving the car, N:

$F_h = M_a j_a$ (2)

j_a is the linear acceleration of a car, m/s^2; Ma is the mass of a car, kg;

F_v is the force of air resistance acting on the car, N :

$F_v = K \cdot F \cdot V_a{}^2$ (3)

K is an air drag coefficient, kg/m^3;

F is frontal area of the car, m^2;

V_a is the speed of the car at the given moment, m/s;

F_i is the force of resistance to acceleration of the car (inertia force), N :

$$F_i = \text{Ma} \cdot j_a \cdot \delta_{ayl} \quad (4)$$

δ_{ayl} is the coefficient taking into account rotating masses of the vehicle.

$$\delta_{ayl} = 1 + \frac{I_{М} \cdot u_{TP}^2 + I_k}{G_a \cdot r^2} \cdot g \approx 1 + (\delta_1 \cdot u_{КП}^2 + \delta_2) \quad (5)$$

$$\delta_1 = \frac{I_M \cdot u_{гл}^2}{G_a \cdot r^2} \cdot g \approx 0{,}04 \ldots 0{,}06; \qquad \delta_2 = \frac{I_k}{G_a \cdot r^2} \cdot g \approx 0{,}03 \ldots 0{,}05;$$

$F_n$is the hill climbing resistance force:

$$F_n = M_a \cdot \mathrm{g} \cdot \sin a \quad (6)$$

g is the acceleration of gravity, $\mathrm{g} = 9{,}81\ m/s^2$;

a is longitudinal slope of the road, %;

F_f is rolling resistance force, N;

f is rolling resistance coefficient.

$$F_f = f \cdot M_a \cdot g \cdot \cos a \quad (7)$$

Equation (1) can be written as following:

$$M_a j_a = M_a \cdot g \cdot \sin a - f \cdot M_a \cdot g \cdot \cos a - Ma \cdot j_a \cdot \delta_{ayl} - K \cdot F \cdot V_a{}^2;$$

$$M_a j_a \left(1 + \delta_{ayl}\right) = M_a \cdot g \cdot \sin a - f \cdot M_a \cdot g \cdot \cos a - \ K \cdot F \cdot V_a{}^2;$$

from that the linear acceleration of the vehicle can be determined:

$$j_a = \frac{M_a \cdot \mathrm{g} \cdot \sin a - f \cdot M_a \cdot g \cdot \cos a - K \cdot F \cdot V_a{}^2}{M_a\left(1 + \delta_{ayl}\right)} \quad (8)$$

Acceleration of the vehicle moving on continuous slope can be expressed:

$$j_a = \frac{V_k^2 - V_b^2}{2S} \ , (9)$$

If equation (9) put to (8) following equation can be achieved:

$$\frac{V_k^2 - V_b^2}{2S} = \frac{M_a \cdot \mathrm{g} \cdot \sin a - f \cdot M_a \cdot g \cdot \cos a - \ K \cdot F \cdot V_a{}^2}{M_a\left(1 + \delta_{ayl}\right)} \quad (10)$$

From this formula, we determine the distance (11) traveled by a car with a broken brake system to reach a critical speed that cannot ensure safety on a continuous slope:

$$S = \frac{M_a\left(1 + \delta_{ayl}\right)\left(V_k^2 - V_b^2\right)}{2\left(M_a \cdot \mathrm{g} \cdot \sin a - f \cdot M_a \cdot g \cdot \cos a - \ K \cdot F \cdot V_a{}^2\right)} \quad (11)$$

Taking into account the fact that air resistance is $0 < F_v \leq 5\%$ of the forces acting on a car with a broken brake system on a continuous slope up to a speed of 60 km/h, equation (11) is expressed as follows:

$$S = \frac{M_a(1+\delta_{ayl})(V_k^2 - V_b^2)}{2M_a(g\cdot \sin a - f\cdot g\cdot \cos a)} = \frac{\frac{1+\delta_{ayl}}{2g}(V_k^2 - V_b^2)}{(\sin a - f\cdot \cos a)} \quad (12)$$

The coefficient for taking into account the rotating masses when trucks move with acceleration is calculated for the case when the gear box is not engaged:

$$\delta_{ayl} = 1 + \frac{I_M \cdot u_{TP}^2 + I_k}{G_a \cdot r^2}\cdot g \approx 1 + (\delta_1 \cdot u_{KП}^2 + \delta_2)$$

$$\delta_1 = \frac{I_M \cdot u_{гл}^2}{G_a \cdot r^2}\cdot g \approx 0{,}04 \ldots 0{,}06; \qquad \delta_2 = \frac{I_k}{G_a \cdot r^2}\cdot g \approx 0{,}03 \ldots 0{,}05;$$

$$\delta_{ayl} = 1 + 0{,}06 + 0{,}05 = 1{,}11; \qquad k = \frac{1+\delta_{ayl}}{2g} = \frac{1+1{,}11}{2*9{,}81} \approx 10^{-1}$$

Formula (12) takes the following view:

$$S = \frac{(V_k^2 - V_b^2)}{10\,(\sin a - f\cdot \cos a)} \quad (13)$$

The distance between the installation of RTR, which ensures the safety of cars whose brakes fail on a continuous slope, is determined by formula (13).

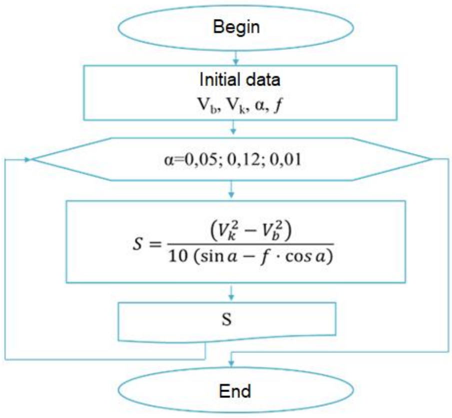
S is the distance between the installation of RTR, m;

V_b is the initial speed of the vehicle, m/s;

V_k is the limited maximum speed of the vehicle ensuring the traffic safety on the road part, m/s.

ANALYSIS AND RESULTS

The algorithm for determining the distance between the installation of safe stopping lanes in the event of a disaster (accident) of a truck on continuous slopes by calculation is shown below:



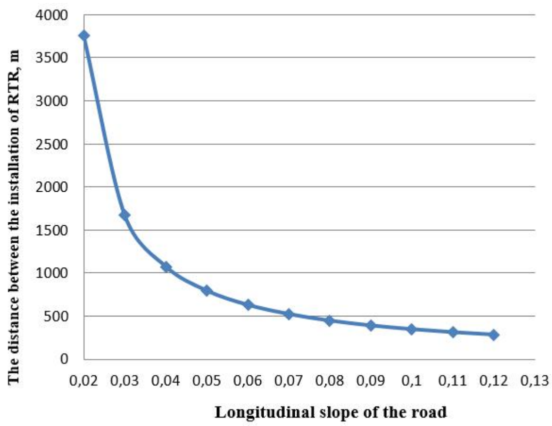


Figure. 2. Relation between RTR installation distance and longitudinal slope of the road.

If there is a vehicle breakdown occurred in the mountain road, the speed of the vehicle will decrease due to vehicle enter to RTR and the road transport accident will be avoided. Runaway truck ramps are important in ensuring the traffic flow safety.

Runaway truck ramps are divided into three types:

gravity, in which the truck will be stopped by hill climbing resistance force;

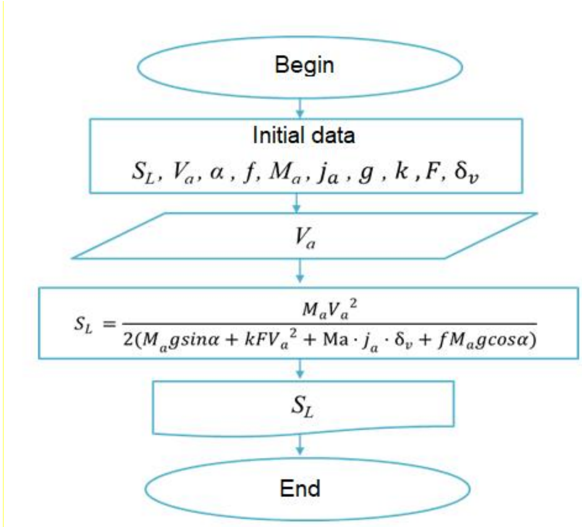
sand pile, where the car's energy is dissipated through the sand pile;

limited bed, in which the movement of the vehicle is braked by the high resistance of the road surface (the road surface is sandy, gravel, earth, etc.).

Limited bed upper class (mixed method), in which the kinetic energy of the car is dissipated by the slope and limited bed horizontal type of road.

Determination of the length and slope of the entrance road, which ensures safe extinguishing of their kinetic energy in the event of catastrophic (accident) movement of cars, was carried out by the MatLab Simulink program.

The algorithm of calculating by mathematic model is given below:



$$\boldsymbol{E_k} + \boldsymbol{E_p} = \boldsymbol{E_t} \quad (14)$$

On mountain roads, the length of RTR can be determined by damping the kinetic energy of vehicles from the longitudinal slope of the road at the expense of the resistance forces acting on the vehicles.

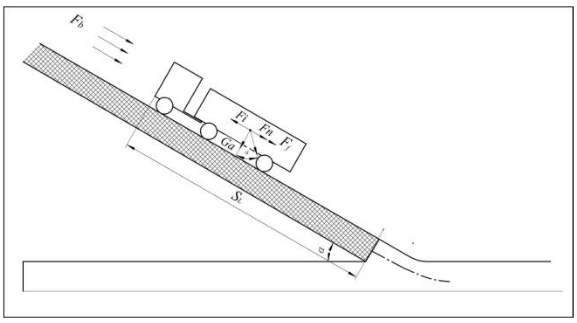


Figure. 3. Forces acting on the vehicle in gravity type of RTR.

$$\frac{M_a {V_a}^2}{2} = (F_f + F_n + F_b + F_i) S_L \cos\alpha \qquad (16)$$

$$S_L = \frac{M_a {V_a}^2}{2(M_a g sin\alpha + kF{V_a}^2 + \mathrm{Ma} \cdot j_a \cdot \delta_v + fM_a g cos\alpha)} \qquad (17)$$

S_L is the length of runaway truck ramp, m;

j_a is deceleration of the vehicle, m/s^2.

In case of disasters, measures such as the installation of access roads, widening of the traffic area in parking lots or rest areas, as well as the widening of road intersections are the most necessary conditions for ensuring safety. If such measures are not provided during the road repair, safety measures should be implemented before the repair. However, the above-mentioned measures cannot exclude the sudden breakdown and stoppage of trucks on the roadway.

Therefore, to develop measures for the evacuation of technically defective vehicles and to determine the distance between the places of installation of RTR and their structural parameters to stop the truck even if the brake system does not work, and preventing dangerous situations on the road in the dark is an issue of economic and social importance.

The calculation result of steep-height RTR using a mathematical model is given below.

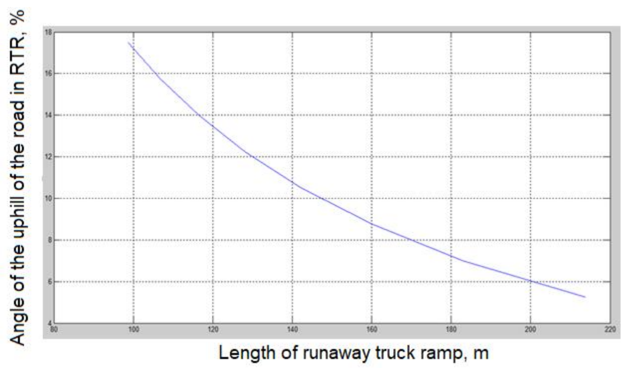


Figure. 4. Relation between length of RTR and angle of the its uphill

By decreasing of the angle of the road the length of RTR is increased according to Fig. 4.

Relation between length of RTR and its slope depending on speeds 50, 60, 70, 80, 90, 100, 110 km/hour of the vehicle on the entrance to RTR is shown in Fig. 5.

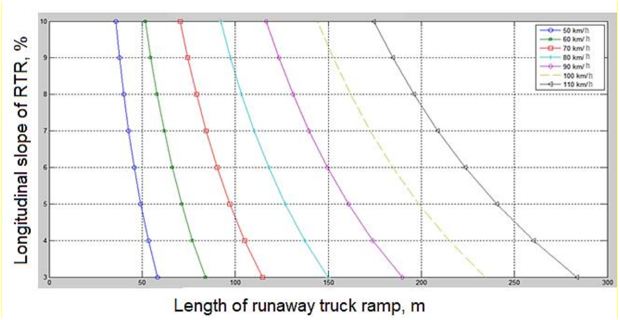


Figure. 5. Relation between length of RTR and its slope depending on speeds of the vehicle

By varying the vehicle's speed length of RTR varies differently depending on its slope.

Relation between length of RTR and speed of the vehicle on the entrance to RTR in slopes of the road 5, 6, 7, 8, 9, 11 and 12% is given in Fig. 6.

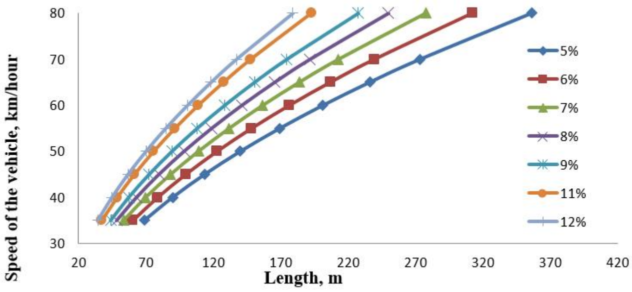


Figure. 6. Relation between length of RTR and speed of the vehicle on the entrance to RTR

We can see from Fig. 6 that length of RTR is in direct ratio with speed of the vehicle and not directly proportional with increasing the slope of the road. The influence between length of RTR with limited bed type and type of the road pavement is shown in Fig.7. By increasing the resistance of the road pavement length of RTR, which ensures traffic safety can be decreased.

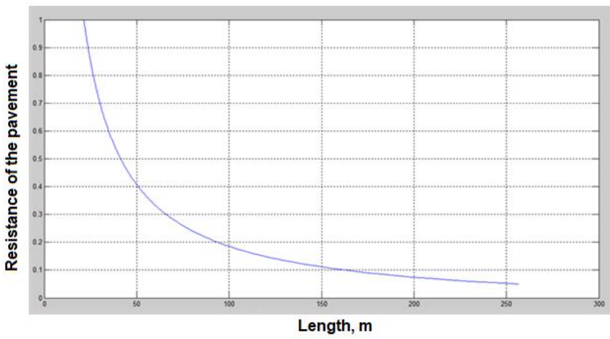


Figure. 7. Relation between length of RTR and resistance of the pavement

It can be seen from Fig. 7 that how big a resistance of the pavement so small the length of RTR. For instance, if resistance of the pavement is φ=0,4 then length of RTR is 50 m and etc.

Knowing this relationship allows for the construction of RTR of different lengths due to the use of road surfaces with high resistance depending on the topography of the mountain roads.

Gravity, limited bed horizontal type and mixed types of RTR can be used to ensure the safety of vehicles. The length of the mixed type RTR (S_1), the length of gravity RTR (S_2) and the length of limited bed horizontal type RTR (S_3) are determined.

$$\frac{1}{S_1} = \frac{1}{S_2} + \frac{1}{S_3} \quad (18)$$

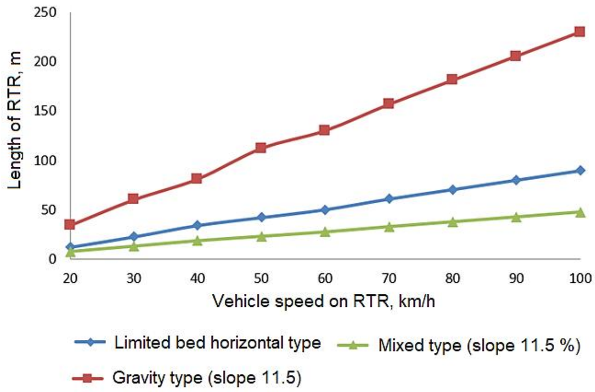


Figure. 8. Relations between length of RTR, speed of the vehicle and type of runaway truck ramp

Runaway truck ramp allows safe stopping a vehicle with a gross weight of 40 tons, which lost control at a speed of 60 km/h on the road with slope 11.5% in 130 meters on a gravity-type RTR, in 50 meters on a limited-bed horizontal-type RTR, 27 meters on a mixed-type RTR (Fig. 8).

CONCLUSION

Topographical analysis of traffic accidents and dangerous sections of the Kamchik pass was carried out and 49 dangerous sections of the pass road were identified. Critical speeds of vehicles were determined on 49 dangerous road sections. The regulatory requirements imposed on RTR and the problems caused by these requirements in practice were analyzed. The existing RTRs in Kamchik pass were analyzed and it was found that 17 existing ones do not meet the regulatory requirements. A method of determining the distance between the installation of RTR in the event of a truck accident on continuous slopes was developed by calculation. Based on the MATLAB/Simulink simulation model, the method of determining the length and slope of the entrance road, which provides safe damping of the kinetic energy of cars in the event of a catastrophic (accident) movement, has been improved. The relationships between the longitudinal slope of the mountain road, the speed of the motor vehicle on different slopes, the weight of the motor vehicle and the installation interval of the RTR were determined. A vehicle with a gross weight of 40 tons, which lost control at a speed of 60 km/h on the road with slope 11.5% is able to stop in 130 meters on a gravity-type RTR, in 50 meters on a limited-bed horizontal-type RTR, 27 meters on a mixed-type RTR.

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Determining the environmental impact based on the tire wear calculation method

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ABSTRACT

Today, environmental protection and reduction of environmental damage is one of the pressing issues on a global scale. Automobile tires used in vehicles also have a serious impact on environmental problems due to wear during operation. This article provides a scientific and theoretical analysis of the tire wear process, and determines the amount of harmful substances emitted into the environment. A calculation method based on the theory of friction and deformation was used to estimate tire deflection. The dynamic characteristics of the car, the distribution of pressure in the contact zone of the tire and the road surface, friction forces and deformation processes were taken into account. The research results revealed the mechanism of material loss in the friction zone formed on the contact surface of the tires. It is shown that the detected solid particles can be emitted directly into the atmosphere, causing air pollution and increasing damage to the environment.

Keywords: Automobile tires, tire deflection, deflection calculation method, friction and deformation theory, contact pressure distribution, friction forces, microparticle emission, environmental pollution, environmental damage.

INTRODUCTION

Today, ensuring environmental sustainability and reducing environmental damage are considered one of the most important tasks worldwide [1]. In particular, cars operating in the transport sector have a significant impact on the environment due to emissions into the atmosphere, fuel consumption, and wear of tires and components [2].

Car tires, in turn, gradually lose their weight due to friction and deformation during operation, and also release harmful microparticles into the environment [3].

According to the results of various studies, rubber and polymer particles emitted into the air during tire wear make a significant contribution to atmospheric pollution [4]. These particles not only aggravate environmental problems, but are also a hazardous factor for human health [5]. Therefore, calculating tire wear and determining its impact on the environment is one of the pressing issues in the modern automotive and environmental sectors [6].

The Archard model was proposed in 1953 by British scientist J. F. Archard and is designed to predict abrasive wear caused by friction [7]. The Rea model empirically describes the wear of the surface of a tire or other elastic body due to friction, relating it to the sliding velocity and contact pressure [8].

The Paceczka model, commonly known as the "Magic Formula", was first developed by Hans B. Paceczka in 1992. It is designed to model the relationship between complex friction forces and the slip angle of a vehicle's wheels relative to the road surface using a simple empirical formula [9]. To solve this problem, a more accurate and physically sound approach is to model tire wear based on friction-deformation theory, i.e. modeling based on forces and energy exchange between the tire and the road. This approach allows us to determine the deformation of the tire material in the contact zone and the sliding conditions, as well as analyze the wear process with high accuracy.

The main objective of this study is to determine the amount of harmful substances emitted into the environment by mathematically modeling tire wear based on friction and deformation processes.

METHODOLOGY

The wear process that occurs between automotive tires and the road surface is governed by two fundamental physical phenomena: friction and deformation. These mechanisms result in the detachment of micro-particles from the tire surface, a phenomenon facilitated by the combined effects of tangential forces, elastic strain, and relative slip motion within the contact area [10].

The portion of the tire that directly interfaces with the road—termed the "contact patch"—constitutes the principal physical domain in which tire-road interaction occurs [10] (see Figure 1). The total force transmitted between the vehicle and the road is concentrated within this region. The tire contact patch can be subdivided into two distinct areas:

- **Adhesion zone**: There is no relative motion between the tire and the road surface. Forces are transmitted entirely through elastic deformation.
- **Slip zone**: Relative sliding occurs between the surfaces, resulting in significant frictional forces, energy dissipation, and intensified tread wear.

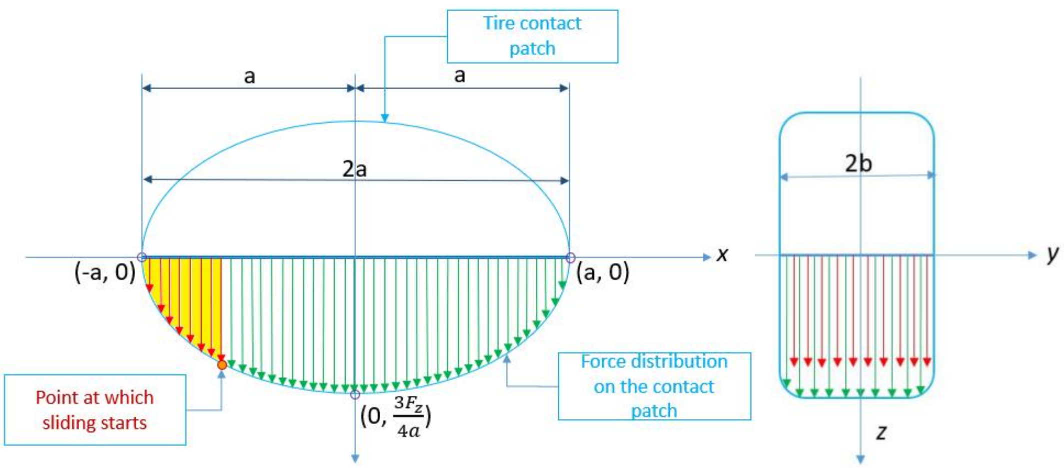

Figure 1: A schematic representation of the tire-road contact patch, pressure distribution, and slip onset region.

The figure above (Fig. 1) schematically shows the distribution of the weight force in the tire contact patch. The shape and size of the tire contact patch with the road change over time. The pressure distribution in the contact patch during movement is symmetrical. That is, when the tire is deformed and dynamically moving, asymmetry occurs, which means that the center of pressure shifts forward or backward from the wheel axis. Thus, a parabolic pressure distribution is insufficient to determine this wear profile.

Such an approach was proposed by Jacob Svendenius and Björn Wittenmark in their study "A model for a flexible brush tire" [11]. In their study, the pressure distribution across the contact patch is modeled using an asymmetric third-order polynomial function. The proposed pressure distribution is expressed as follows (1)

$$q_z = \frac{3F_z}{4a}\left(1-\left(\frac{x}{a}\right)^2\right)\left(1+d\cdot\frac{x}{a}\right) \qquad (1)$$

Where:

- q_z —vertical force per unit length (N/m)
- F_z — vertical force (N),
- a — half of the contact length (i.e., $x \in [-a, a]$),
- d — the asymmetry coefficient, representing the shift of the pressure center within the contact zone.

In the above expression, the first multiplicative term, $\left(1-\left(\frac{x}{a}\right)^2\right)$, defines a parabolic pressure shape that reaches its maximum at $x = 0$ and becomes zero at the boundaries $x = \pm a$. The second term, $\left(1+d\cdot\frac{x}{a}\right)$, introduces asymmetry into the pressure distribution and accounts for the shift in the pressure profile [11].

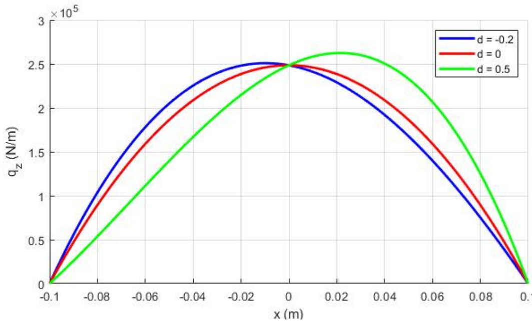

Figure 2: Distribution of vertical force per unit length along the tire–road contact patch.

One of the key advantages of this model is that it employs a normalized formulation, which ensures that the total vertical force per unit length remains equal to F_z regardless of the selected value of d.

$$F_z = \int_{-a}^{a} q_z(x)\, dx \qquad (2)$$

This condition guarantees the conservation of the total normal force for any vertical force profile defined per unit length. As a result, the parameter d only alters the geometric distribution of the vertical force per unit length but does not affect the overall contact force [11].

To determine the boundary between slip and adhesion, the force equilibrium at each point along the contact patch is analyzed. When the elastic deformation of the tire reaches the onset of sliding, the tangential elastic force in that local element becomes equal to the corresponding frictional force. This condition allows the identification of the slip onset location, denoted as x_s, within the contact zone.

Slip initiation occurs when the elastic deformation of the tire reaches a threshold where it balances the maximum available friction force. This equilibrium condition is described by the following algebraic equation [11]:

$$c_p \cdot \sigma_x \cdot (a - x_s) = \varphi \cdot q_z(x_s) \qquad (11)$$

Where:

- c_p — stiffness coefficient
- σ_x — slip ratio
- a — half-length of the contact patch

- φ — coefficient of adhesion (friction coefficient);
- $q_z(x_s)$ —vertical pressure value at the slip onset point x_s.

The equation can be rewritten in expanded form as follows:

$$c_p \cdot \sigma_x \cdot (a - x_s) = \varphi \cdot \frac{3F_z}{4a} \cdot \left(1 - \left(\frac{x_s}{a}\right)^2\right) \cdot \left(1 + d \cdot \frac{x_s}{a}\right) \quad (12)$$

This expression results from solving the square root–based rational equation and takes the following form:

$$x_s = \frac{a}{2d(d+1)} \cdot \left((d+1)^2 - \sqrt{(d+1)^4 - \frac{16 \cdot c_p \cdot a^2 \cdot d \cdot \sigma_x}{3 \cdot \varphi \cdot F_z}}\right) \quad (13)$$

sliding friction force in the slip zone

$$\sum F_s = \mu \cdot \int_{-a}^{x_s} q_z(x) dx \quad (14)$$

The normal pressure q_z, generated in the contact zone between the tire and the road is typically modeled as a distribution along the direction of motion, i.e., along the x -axis. However, the actual contact zone is not one-dimensional; it is a two-dimensional surface bounded in both the longitudinal (x) and lateral (y) directions.

In reality, the pressure is not uniform across the width of the tire surface (the y -axis); rather, it tends to decrease from the center toward the edges. By incorporating the exponential decay of pressure away from the center in the lateral direction, the pressure distribution can be expressed as follows:

$$q_z(x, y) = \frac{3F_z}{4a} \left(1 - \left(\frac{x}{a}\right)^2\right)\left(1 + d \cdot \frac{x}{a}\right) \cdot \exp\left(-\left|\frac{y}{b}\right|^n\right) \quad (15)$$

To accurately represent the overall contact pressure distribution from both physical and mathematical perspectives, the pressure must vary not only along the longitudinal direction (x) but also across the lateral direction (y) of the tire.

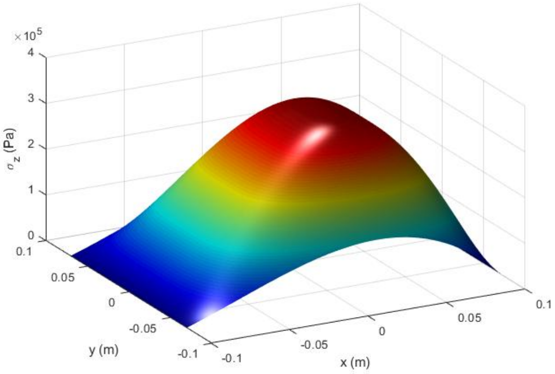

Figure 3: Three-dimensional pressure distribution over the tire–road contact surface.

The total normal force exerted by the tire on the road is determined by integrating the distributed normal pressure over the contact surface. This force is expressed through a two-dimensional integration over the contact zone as follows [12]:

$$F_z = \frac{3F_z}{4a} \int_{-a}^{a} \left(1 - \left(\frac{x}{a}\right)^2\right)\left(1 + d \cdot \frac{x}{a}\right) dx \cdot \int_{-b}^{b} \exp\left(-\left|\frac{y}{b}\right|^n\right) dy \qquad (16)$$

Moreover, the pressure at each point within the contact area defines the local force contribution, and the total tire force is obtained by integrating these contributions over the entire contact patch.

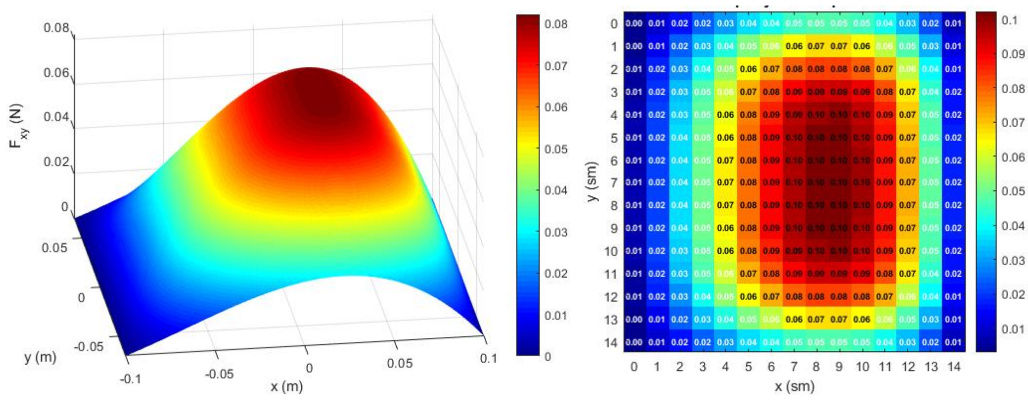

Figure 4: Three-dimensional and heatmap visualization of pointwise tangential force distribution on the contact surface.

In the slip zone ($x \in [-a, x_s]$), the tangential force density generated over the contact surface represents the frictional forces arising from the relative motion (slip) between the tire and the road. This force density is directly related to the pressure distribution and the frictional characteristics of the contacting materials, and it is defined by the following expression:

$$\sum F_s = \mu \cdot \frac{3F_z}{4a} \int_{-a}^{x_s} \left(1-\left(\frac{x}{a}\right)^2\right)\left(1+d\cdot\frac{x}{a}\right)dx \cdot \int_{-b}^{b} \exp\left(-\left|\frac{y}{b}\right|^n\right)dy \qquad (17)$$

This 3D plot shows the distribution of tangential forces over the contact surface. The color gradient indicates the force magnitude (blue - low, red - high). The green plane represents the boundary of the slip zone at the point x_s. This boundary is determined based on contact elasticity and the level of friction.

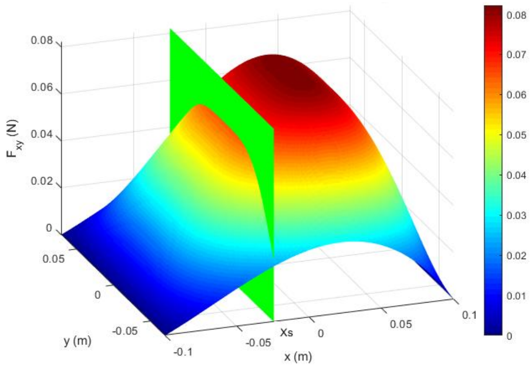

Figure 5: Vertical force distribution and slip zone boundary point

Material wear occurs at the contact interface between the tire and the road due to elastic deformation and frictional effects. A widely used approach to quantify this physical phenomenon is the Archard model, which describes the volume of material loss resulting from pressure-induced deformation during sliding contact. The general form of the Archard wear model is expressed as follows:

$$W = k \cdot \frac{F_n \cdot s}{H} = k \cdot \frac{3F_z \cdot s}{4a \cdot H} \cdot \int_{-a}^{x_s} \left(1-\left(\frac{x}{a}\right)^2\right)\left(1+d\cdot\frac{x}{a}\right)dx \cdot \int_{-b}^{b} \exp\left(-\left|\frac{y}{b}\right|^n\right)dy \quad (18)$$

This expression represents the material loss over the slipping region of the tire, considering the two-dimensional pressure distribution across both the longitudinal and lateral directions of the contact surface. The Archard model is used in the brush model but includes a portion of the tire in the sliding zone where gravity forces are applied to account for tire wear.

CONCLUSION

The proposed calculation method, based on the theory of friction and deformation, made it possible to determine the intensity of tire wear and estimate the amount of harmful particles formed. This, in turn, is of great practical importance for the scientific accounting of environmental damage caused by tires and the development of resource-saving measures. Based on the results obtained, a number of practical recommendations can be developed in the field of efficient use of tires in vehicles, improvement of recycling processes and environmental protection. This will allow us to take important steps towards ensuring environmental sustainability and implementing resource-saving technologies in our country.

ACKNOWLEDGEMENT

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The brief review of the influence of variable depth tillage on tractor fuel consumption

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INTRODUCTION

Tillage is one of the most significant operations in agricultural production, that influences not only soil health and crop yield but also energy use. The tilling process of the earth takes over a high percentage of the energy use in farming activities which constitutes 35-40 percent of the total field work energy use [1]. In order to achieve more sustainable agriculture, the issue of reducing the energy consumption of tillage activities, especially the use of fuels, has become a top priority [1]. Variable depth tillage (VDT) may provide a viable solution to the optimization of energy consumption. With VDT, the degree of soil disturbance can be adjusted to meet soil characteristics and crop demands. This paper briefly reviews how VDT affects fuel consumption, and it examines how the tillage depth, soil compaction, and tractor performance related.

TILLAGE AND ENERGY CONSUMPTION

Tillage is an energy-demanding activity, and its efficiency is important for the sustainability of the farming operations. During plowing, involved with the process of tilling, tractors need to develop large draft forces in order to loosen the soil, and as a result, consumes a lot of fuel. Mamkagh [2] has demonstrated that more than half of the total diesel usage in a farming activity may be attributed to tillage activities, particularly plowing. The deeper the tillage depth is the higher the draft force necessary to push the plow in the soil [2]. Consequently the more energy is consumed by tractor.

In existing literature, several ways have been investigated to decrease fuel usage in the process of tillage such as enhancements in the slippage of the wheels, tractor performance and the depth of tillage. Although reducing the tillage depth is a primary way of saving fuel, agronomic advantages of deep tillage must be weighed against this, where in some situations it may enhance root development and improve soil structure. This leads to the idea of variable depth tillage where the depth of the tilling can be altered due to certain circumstances in the field.

Variable Depth Tillage

Advanced tillage machinery makes it possible to use variable depth tillage systems that allow the adjustment of the tillage depth to the conditions of the soil that vary. These are the systems which may adjust the depth according to the factors like soil texture, moisture, and compaction according to the sensors and real-time data. Among the advantages of variable depth tillage, there are better water retention and soil structure, and it may also be beneficial in terms of fuel savings [3-6].

The effect of varying depth tillage on consumption of fuel mainly depends on the level of soil disturbance. Under conventional tillage techniques in which depth is constant throughout the field, the tractor has to operate at constant power output. In contrast, in variable depth tillage, the tractor can adapt to the volume of work required, and less of its fuel is used in those regions that do not need as much disturbance. Energy utilization can be optimized by being able to adjust the depth of tillage to the particular requirements of the soil.

Compaction of Soil and Fuel efficiency.

The degree of soil compaction determines the quantity of energy that is needed when carrying out tillage activities [5,6]. Compressed soils are difficult to penetrate by tillage-tools, which also demands increased draft-force and thus increased fuel [3].

Reducing compaction and allowing plant roots to penetrate the soil easier is one of the aims of tillage. But excessive deep tilling may result in formation of a hardpan beneath the tilled layer that may enhance subsequent compaction and fuel demands in subsequent operations [5,6].

Variable depth tilling allows farmers to avoid excessive tilling of surfaces whose soil is already loose or to till more deeply in surface areas that are heavily compacted. Such a selective tillage can prevent the needless waste of energy, as well as save the structure of the soil. Subsequently, fuel is reduced since the tractor is not working to full capacity when not required.

Effects of Tillage Depth on Tractor Performance.

The draft force depends on depth of plowing that determines tractor’s fuel consumption when plowing with a tiller. Investigations by Kim et al. [7] indicate that the amount of force needed to perform the tillage process increases with the depth of the plowing task, that causes fuel consumption to rise. Draft force in traditional tillage is usually determined by means of load cells, and it has been found that much deeper tilling causes draft forces to increase dramatically [7].

Variable depth tillage works by keeping the depth of tillage at a constant depth in the field in accordance with the specifics of the soil, or one specific zone will need deep tillage and another shallow, due to the absence of a need to bring up deep soil. Such draft force optimization can lower fuel consumption of the tractor, since the engine does not operate at high loads during the whole field. Thus, tractors may work more effectively due to the reaction to the real-time data about the soil by reorganizing the depth of tillage, which reduces fuel consumption and makes the method of farming more sustainable.

Improvement in Tillage machines.

New technologies in tillage have boosted the ability to apply variable depth tillage. As an illustration, a tillage depth measurement system can be used to ensure an accurate control of tillage depth during operation; this is a system equipped with a sensor (optical distance sensors, linear potentiometers, inclinometers, etc.) [7]. Such systems sense the depth and the condition of the soil, and the tractor can also change the depth of tillage. Moreover, draft force sensors have been introduced to the tractors to give real-time information on the fuel consumption and soil conditions and make adjustments immediately during operation [2]. Such technological improvements have the positive effect of making the process of tillage much more precise, as well as potentially saving on fuel. Energy efficiency of tillage operations is greatly enhanced by enabling the tractors to vary their draft force and tillage depth according to actual soil conditions [8,9].

CONCLUSION

Variable depth tillage can provide great promise in fuel reduction in farming. The energy demanded in the tillage operations can be reduced by changing the tillage depth based on the conditions of the soils. Tillage depth is closely correlated with soil compaction, draft force, and tractor performance and variable depth tillage systems enable these variables to maximize fuel savings. With the increasing adoption of variable depth tilling trailed by the rise in use of accuracy-based farming equipment, the practice may be very instrumental in ensuring that agriculture is more energy conscious and sustainable.

Further work on sensors to enhance precision of measurements, and more effective tractor systems to realize the advantages of variable depth tillage must be carried out in the future to improve fuel consumption and general productivity of the farm.

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URBAN MOBILITY AND THE TRANSITION TO ELECTRIC TRANSPORTATION

Analysis of factors affecting the safety of bicycle traffic in cities

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ABSTRACT

This article aims to analyse the factors affecting the safety of bicycle traffic in cities. The work studies the current state of bicycle use and identifies the main factors affecting safety, such as infrastructure, climatic conditions, and human factors. The article evaluates the safety problems of cyclists based on the results of a questionnaire and statistical analysis methods. Based on the results obtained, proposals and recommendations are developed to improve the safety of bicycle traffic in cities.

Key words: cyclists, infrastructure, bicycle traffic safety, statistics, questionnaire, respondent, cyclists, urbanization, sustainable transport.

INTRODUCTION

Currently, the sharp increase in traffic jams in large cities with a high population in Uzbekistan increases the need to develop a sustainable transport system in our country. The use of bicycles is an integral part of this sustainable transport system. Despite the fact that bicycles are an environmentally friendly, economically viable and healthy means of transport, their safety remains one of the most important problems. And in our cities, such safety problems prevent volunteers from using bicycles as a means of transport for daily commutes. Although many countries have created a convenient infrastructure for cyclists, the use of bicycles in our country, including in Tashkent, has not yet become widespread.

The increase in car traffic in large cities is prompting passengers to choose bicycles, considered “micro mobility” for convenient distances of 1-10 km, and as a result, the number of road accidents involving bicycles is increasing sharply. According to the 2023 report of the World Health Organization, more than 1.35 million people die in road accidents worldwide every year, and 3% (40,500) of them are cyclists. In the Republic of Uzbekistan, 492 road accidents involving bicycles were recorded in the first eight months of 2020, resulting in 143 deaths. Accidents involving cyclists accounted for 14% of the total road accidents in 2020. The number of accidents involving cyclists in Uzbekistan was 1,075 in 2021 and 1,136 in 2022, respectively. [7,8]

Studies show that 53.7% of road accidents involve pedestrians and cyclists. 57% of these accidents are caused by deficiencies in road infrastructure and 43% by drivers not following traffic rules. According to the analysis, the main factors in accidents involving cyclists in our cities are inadequate infrastructure and insufficient driver skills. Countries with developed cycling, such as the Netherlands, Denmark, Germany, Belgium, France, China and Japan, have managed to increase the attention of drivers and thus ensure the safety of cyclists by increasing the attractiveness of cycling, in addition to reducing both causes of accidents. [9,10]

This article aims to study the demand for bicycle transport in cities through a questionnaire and to identify factors affecting the safety of bicycle traffic, as well as to develop scientifically based proposals as a solution. The research uses questionnaire and statistical analysis methods to develop practical recommendations for systematic measures aimed at tackling problems related to the safety of cyclists.

LITERATURE REVIEW

The number of scientific studies on the safety of cycling in urban environments is increasing year by year. Many international studies have analysed the importance of road infrastructure, traffic flow and human factors in ensuring the safety of cyclists. The development of cycling infrastructure, safety measures and their effectiveness in Germany, the Netherlands and Denmark have been analysed by European scientists to improve cycling safety. The results of the study show that the presence of special cycle paths plays a significant role in improving cycling safety. In addition, a report published by the European Commission presents legal and technical requirements for creating a safe environment for cyclists. It has developed recommendations for the creation of special lanes, traffic light systems and low-speed zones to reduce road accidents involving cyclists. [1,2]

Many experimental studies have been conducted to identify the main factors affecting the safety of cyclists. Some studies have identified the speed and density of traffic between cars and bicycles as the main factors affecting the safety of cyclists. Another challenge for cyclists is that climate and seasonal weather conditions significantly affect cycling. In addition, since cyclists have different levels of behaviour and road culture, the level of compliance with traffic rules, experience and awareness of cyclists also play an important role in traffic safety. [3,4,5]

Although scientific research on bicycle safety in Uzbekistan is not yet sufficiently developed, some sources cover current issues in this regard. Projects implemented within the framework of the "Green Transport" program of the President of the Republic of Uzbekistan are aimed at developing bicycle traffic in urban environments. Bicycle lanes have been established on some main roads in Tashkent. However, their safety level does not fully meet international standards. In recent years, the number of scientific works on road safety and environmentally sustainable transport in Uzbekistan has been increasing. An analysis of the literature shows that international experiences on bicycle safety in cities are sufficiently developed and can be adapted to the conditions of Uzbekistan. [6]

METHODS

This study is based on analytical approaches and aims to identify and assess factors affecting bicycle safety in urban environments. The study used survey, statistical analysis, and data mining methods. The following data were collected for the study:

- survey results. A special survey was conducted to study the opinions of city residents, cyclists, and transport experts.
- on-site observation. Observation was conducted to assess the real conditions for bicycle safety in the city.

- analysis of existing documents. Regulatory documents on the urban transport system and bicycle infrastructure, as well as statistics on road traffic accidents, were studied.

The survey was conducted online and in person, and a total of more than six hundred volunteers participated. The questions covered the following main areas:

- existing problems with bicycle safety.
- advantages of using bicycles and the opinions of volunteers.
- reasons for not using bicycles.

RESULTS

A social survey was conducted among transport experts and entrepreneurs to study the need for bicycle transport in cities and to identify the reasons why volunteers do not use bicycles for daily commutes to work or school. The survey was designed to assess the current state of sustainable transport development and includes questions in five areas. One of the areas is specifically designed for bicycle transport and is aimed at studying the existing problems.

The survey results showed that almost half of respondents use passenger transport, while 38 percent choose public transport. About 10 percent of participants said they walk to work, and less than 10 percent use bicycles. (Figure 1).

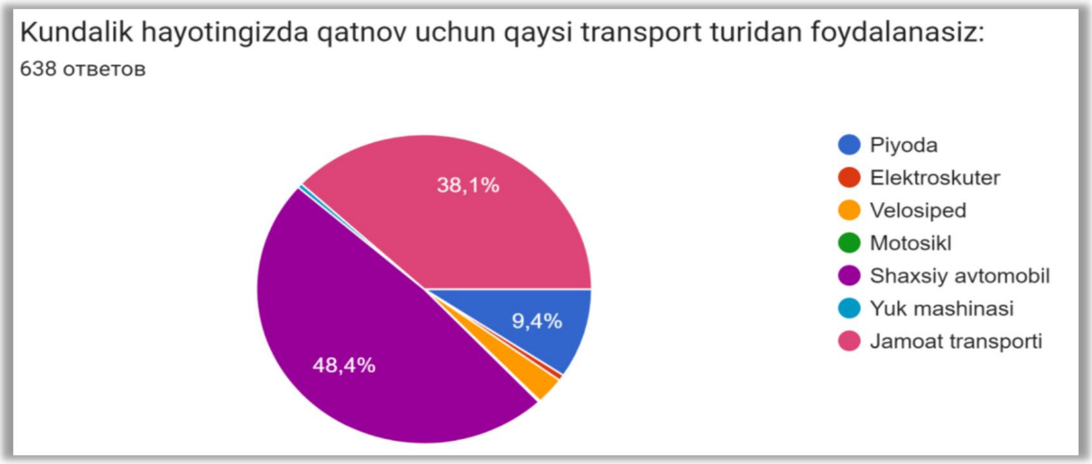

Figure 1. Share of transport users.

53.4% of respondents indicated that they travel more than 10 km every day. It can be assumed that these individuals used passenger transport and, to a lesser extent, public transport. Approximately 22% of respondents indicated that their daily travel distance was between 5 and 10 km. Approximately one fifth of respondents indicated that their daily travel distance was between 2 and 5 km.

The majority of respondents (60%) indicated that they would consider using a bicycle to commute to work, school or shopping facilities every day. Approximately 18% of respondents indicated that they would not use a bicycle as a means of daily transportation. The majority of respondents (77%) indicated that they believe that cycling makes a positive contribution to their health and well-being. A significant decrease in the share of undecided individuals and a slight increase in the number of those with a negative attitude can be observed. The latter may be related to concerns about personal safety.

Respondents showed a high level of awareness of the environmental benefits of cycling compared to driving. 74% of respondents indicated that they were aware of the benefits of cycling, while a smaller proportion considered them to be either unaware or unimportant. The results show that approximately 45% of respondents were satisfied with the quality of cycle paths in their city. However, more than 40% of respondents expressed a negative opinion about the quality of cycle paths. The survey showed that approximately 32% of respondents felt safe when cycling in their city (especially at night), while 43% felt unsafe. (Figure 2)

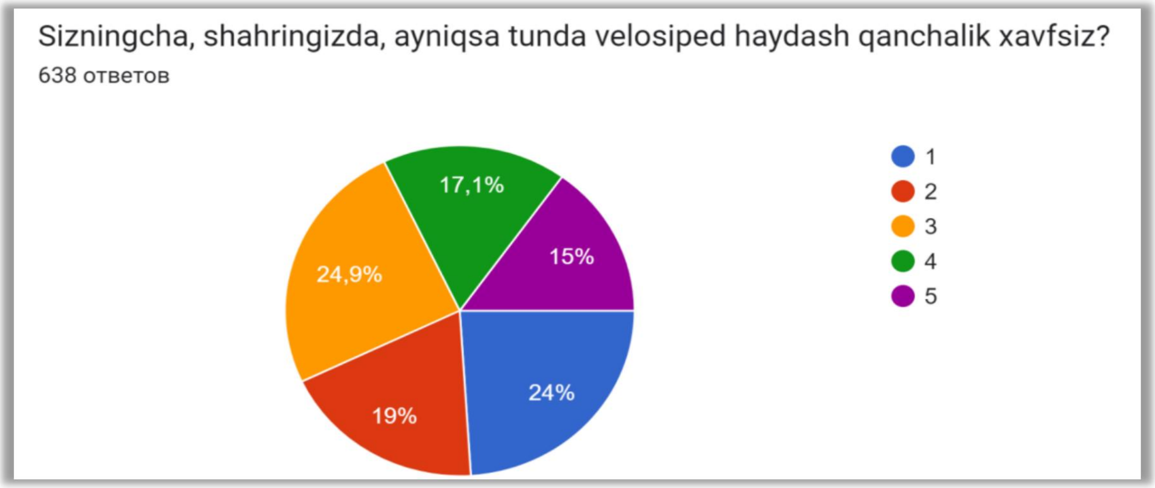

Figure 2. Safety status of bicycle use.

The highest number of respondents, 45.3 percent, expressed concern about the lack of infrastructure, followed by limited bicycle access in their area and the high cost of such sustainable modes of transport. (Figure 3)

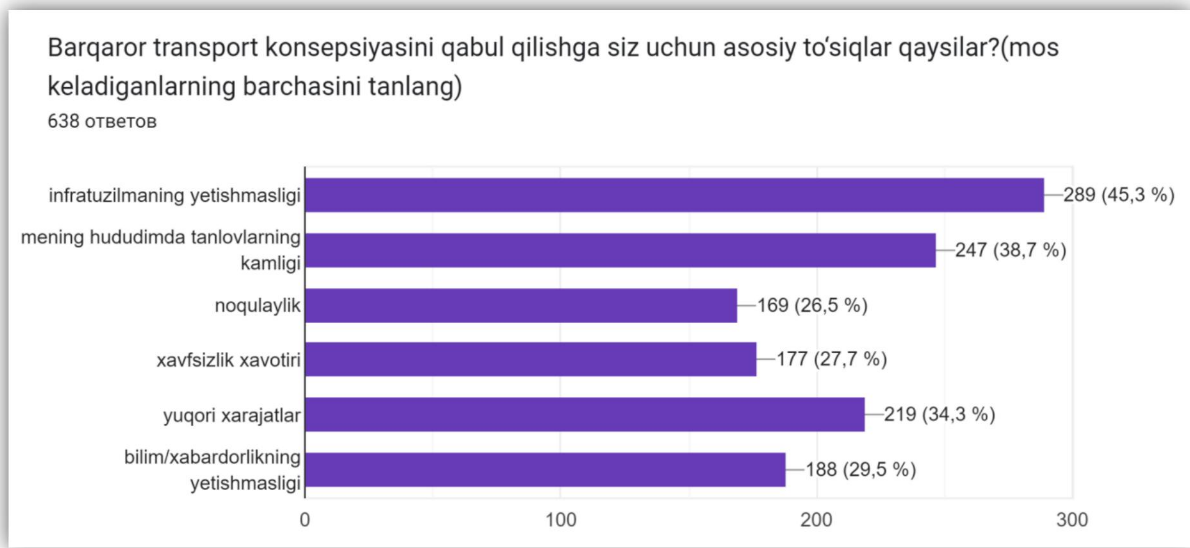

Figure 3. Reasons not to use sustainable transportation.

Also, about 28% of participants stated that the main reason for not using a bicycle was safety concerns.

The study identified a number of infrastructure deficiencies in cities that hinder the use of bicycles by residents: (Figure 4)

- cyclists encounter obstacles such as concrete, ditches, and retail stalls, and cars often use bike lanes as parking spaces;
- pedestrians encroach on bike lanes, obstructing cyclists' movement;
- the width of bike lanes on some streets does not meet international standards;
- bike lanes are scattered and not connected to each other. As a result, cyclists are forced to ride on the carriageway.

Figure 4. Problems with bicycle infrastructure.

According to another source, in 2022, 9,902 road accidents were officially recorded in Uzbekistan, of which 1,136 (11.5%) involved cyclists. In 342 (3.5%) cases, the lack of bicycle lanes was the cause.

DISCUSSION

By analysing the above-mentioned data and foreign experiences on this issue, the following recommendations were developed to increase the level of use of bicycles by the population for daily trips by increasing the safety of bicycle traffic in cities:

- unobstructed movement of bicycle paths, i.e., continuous monitoring of bicycle paths and measures to eliminate illegal obstacles, and the development of strict measures to prevent cars from using bicycle paths as parking lots.

- reducing pedestrian access to bicycle paths, i.e., clearly separating bicycle paths from pedestrian paths and promoting them through appropriate signs and information media.

- aligning the construction requirements for bicycle paths with international standards, i.e., analysing current road standards and comparing them with international standards.

- ensuring the continuity of bicycle paths, i.e., developing strategies for connecting bicycle paths in urban infrastructure planning and optimizing routes.

Measures such as the above are also of great importance in making cycling more attractive on city streets.

CONCLUSION

In conclusion, as a result of the study of the current state of bicycle infrastructure, a number of problems were identified, such as illegal occupation of sidewalks, use of bicycle paths by cars as parking lots, lack of continuity of bicycle paths, improper use of sidewalks by pedestrians at intersections, and failure of sidewalks to meet international standards. The results of the questionnaire and observational study confirmed that these problems cause significant inconvenience to cyclists. The participants noted that the quality and safety of bicycle paths are at a low level and put forward various proposals for improving the sidewalks. In their opinion, improving the existing infrastructure will contribute to the popularization of bicycle transport, improving the urban ecology, and increasing road safety.

A number of measures developed to eliminate the problems during this study serve as the basis for developing effective strategies to improve bicycle infrastructure and make the urban transport system more convenient and safer.

ACKNOWLEDGEMENT

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Safety and sustainable mobility of pedestrians: a case study of the Republic of Serbia

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ABSTRACT

The rapid growth of motorized traffic in recent decades poses a significant challenge to the quality of life and the sustainability of urban environments, while walking, as the simplest and most accessible form of mobility, plays a key role in the development of a sustainable transport system. The aim of this study is to analyze pedestrian safety and public perceptions of walking in the Republic of Serbia during the period 2022–2024.

The results indicate that, during this period, a total of 370 pedestrians were fatally injured in traffic accidents, while 7,892 people were injured, with over 95% of all accidents occurring in urban areas. The highest number of fatalities was recorded during the winter months and transitional periods, highlighting the importance of seasonal conditions and visibility in risk assessment. Simultaneously, a survey of public attitudes reveals a high level of awareness regarding the health, environmental, and economic benefits of walking, but also a pronounced dissatisfaction with the quality of infrastructure and the sense of safety, particularly in urban areas at night.

More than half of respondents believe that walking should be a priority in urban planning, demonstrating citizens' willingness to support measures to improve the pedestrian environment. The combination of an analysis of objective accident data and subjective pedestrian perceptions provides a comprehensive insight into the challenges and potential of walking, emphasizing the need for integrated measures that simultaneously enhance safety and promote sustainable mobility in urban settings.

INTRODUCTION

In recent years, an increase in motorized traffic has been observed, which significantly negatively impacts the quality of life in urban areas. This problem of rising motorized traffic highlights the limitations of urban life to such an extent that the issue of sustainability has become a highly significant topic. Creating a sustainable transport system must be the goal of many global and national strategies related to sustainable mobility. A primary driver for developing a sustainable transport system is the promotion of walking. Walking can contribute to traffic sustainability to a great extent, particularly due to its health, universality, accessibility, and cost-effectiveness.

The role of walking in the urbanization process can be considered a key element of urban planning, as it addresses the needs of pedestrians. Pedestrian needs are often linked to the walking environment, which can be assessed using various tools. One such tool is the Pedestrian Environmental Quality Index (PEQI), developed by the San Francisco Department of Public Health to evaluate the quality of the physical pedestrian environment and to define planning needs for pedestrian infrastructure (Anapakula & Eranki, 2021). The PEQI Index includes indicators reflecting the quality of the built environment that encourages walking, organized into the following main categories: pedestrian safety, street design, traffic, and land use. Among these categories, pedestrian safety occupies a primary position, which also serves as the motivation for this study.

With increasing motorization, preventing traffic accidents and the injuries they cause is becoming an ever greater social and economic challenge, especially in low- and middle-income countries (Pljakić et al., 2025). If current trends continue, road traffic injuries will dramatically increase in most parts of the world over the next two decades, with the most vulnerable citizens being most affected. Globally, approximately 1.3 million people die in traffic annually, making it a leading cause of death among children and young people (ages 5–29) (WHO, 2023). Pedestrians account for nearly a quarter of all road traffic fatalities, and pedestrian deaths are increasing almost twice as fast as fatalities in all other types of traffic accidents (WHO, 2023). Traffic accidents involving pedestrians, like all other road incidents, should never be accepted as inevitable, as they are predictable and preventable. Key risk factors for pedestrian injuries include the lack of safe infrastructure, excessive vehicle speed, alcohol consumption by drivers and pedestrians, and insufficient pedestrian visibility.

Analyzing pedestrian behavior and their perception of risk is a crucial step in understanding the factors affecting traffic safety. The way pedestrians assess danger, make decisions, and choose routes directly influences the frequency and severity of traffic accidents involving them. Risk perception often does not fully align with objective conditions—pedestrians may underestimate dangers in familiar environments or overestimate risks in unfamiliar ones, affecting their behavior. Understanding these patterns allows the identification of critical points in urban areas, the planning of infrastructure that reduces exposure to hazards, and the implementation of educational campaigns aimed at modifying risky behaviors. Simultaneously, investigating attitudes toward the benefits of walking and willingness to engage in pedestrian activity contributes to the development of sustainable urban planning strategies that combine safety, health, and quality of life.

To promote walking effectively, it is necessary to analyze the current state of pedestrian needs. This requires examining both pedestrians' attitudes and their safety while navigating streets. This study addresses both aspects, analyzing pedestrian casualties in the Republic of Serbia and, in parallel, conducting a survey of public attitudes toward walking, behavior, and risk perception.

METHODOLOGY

The study was designed to encompass two complementary approaches, with the aim of examining pedestrian issues from the perspectives of safety and sustainable mobility. The first part involves an analysis of pedestrian casualties in traffic accidents in the territory of the Republic of Serbia during the period 2022–2024. For this segment, data were obtained from the official records of the Traffic Safety Agency of the Republic of Serbia, providing a precise and reliable insight into the scope, structure, and characteristics of pedestrian vulnerability. The analysis includes the identification of the most common causes of accidents, spatiotemporal patterns, and the demographic characteristics of the victims, thus providing an empirical basis for understanding the key risks to which pedestrians are exposed. Figure 1 presents a spatial analysis of traffic accidents involving pedestrians in the Republic of Serbia.

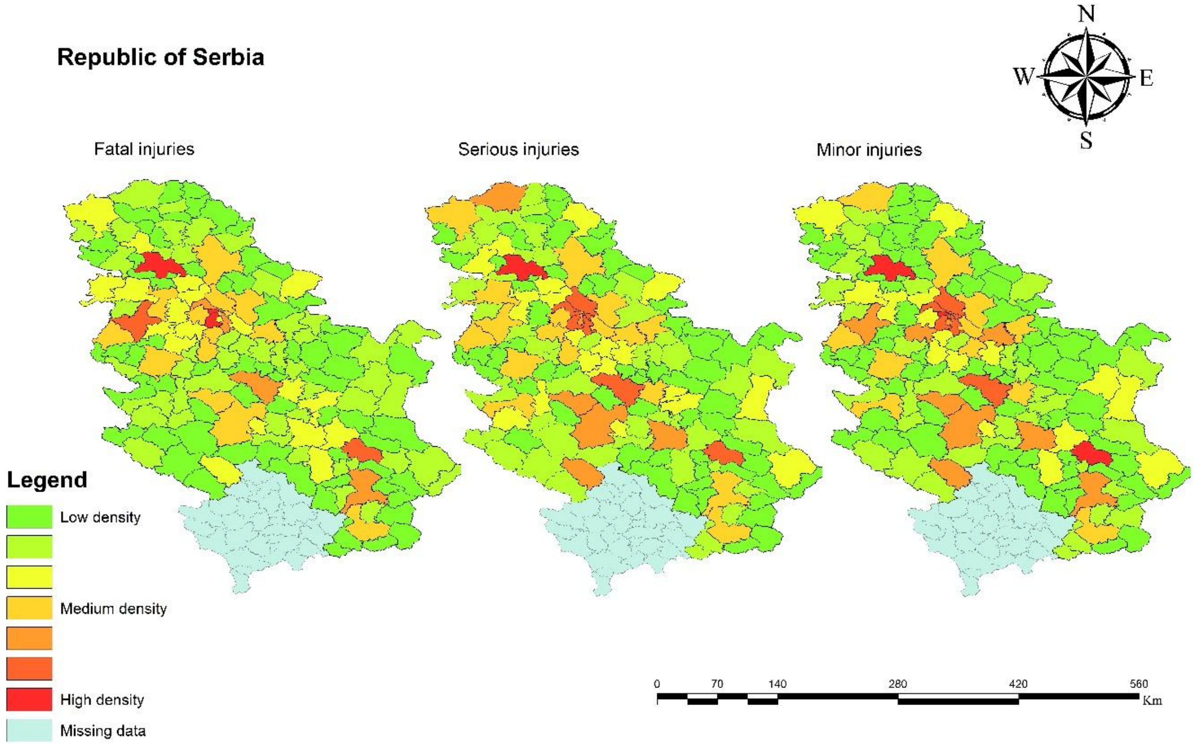

Figure 1. Spatial distribution of pedestrian fatalities in the Republic of Serbia (Pljakić et al., 2025)

The second part of the study was conducted through a survey carried out in 2024 within the framework of the SPHERE project, aimed at collecting the opinions and experiences of experts in traffic, urban planning, and sustainable mobility. A total of 208 respondents from various sectors (public policy, traffic planning, public transport, environmental protection) participated in the survey, allowing the formation of a specialized sample with direct insight into the state and perspectives of pedestrian mobility.

The questionnaire was divided into three thematic sections: (1) sociodemographic characteristics of respondents, (2) assessment of the current state and challenges related to walking, including infrastructure deficiencies, safety risks, and connectivity with other modes of transport, and (3) proposals for improving pedestrian conditions and enhancing their safety. By combining the statistical analysis of pedestrian casualties with the survey results, a comprehensive understanding of existing problems and potential solutions was obtained, forming the basis for recommendations aimed at increasing safety and promoting walking as a key element of sustainable mobility.

RESULTS

1.1. The analysis of pedestrian casualties

The analysis of pedestrian casualties in traffic accidents in the territory of the Republic of Serbia during the period 2022–2024 shows that a total of 370 pedestrians were fatally injured, with 2,377 recorded as seriously injured and 5,515 as slightly injured. The total number of injured and deceased pedestrians during this period amounts to 7,892. Previous research has indicated that analyzing the impact of traffic and infrastructure characteristics on pedestrian accidents demonstrates that certain factors—such as the length of state roads, unclassified streets, the number of bus stops, and parking spaces—significantly increase the risk of accidents in the Republic of Serbia (Pljakić et al., 2022).

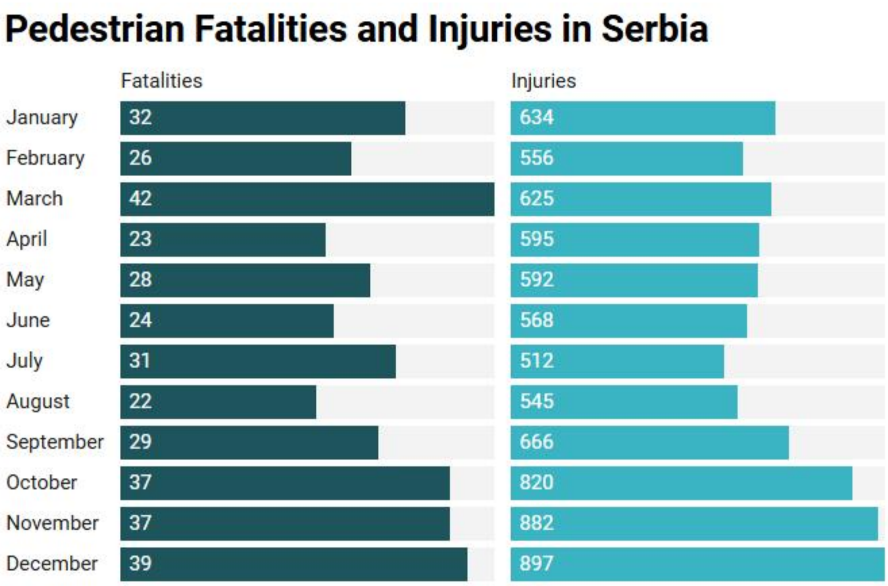

Figure 2. Pedestrian Casualties in Serbia by Month (2022–2024)

Figure 2 presents the number of deceased and injured pedestrians by month. The highest number of fatalities was recorded in March (42), December (39), and October and November (37 each), indicating an increased risk during the winter months as well as transitional periods when weather conditions are challenging and visibility is reduced. The lowest number of fatalities was registered in August (22), which can be associated with reduced traffic intensity during the summer months.

Regarding injuries, December also stands out as the month with the highest number of seriously and slightly injured pedestrians (290 seriously and 607 slightly injured), while the fewest injuries were recorded in August. Spatial distribution analysis shows that the majority of traffic accidents involving pedestrians occurred in urban areas. In these areas, 263 fatalities, 2,202 serious injuries, and 5,324 minor injuries were recorded, accounting for over 95% of all pedestrian casualties. Outside urban areas, the number of casualties is significantly lower—107 fatalities, 175 serious injuries, and 191 minor injuries. These findings clearly indicate that pedestrians are particularly vulnerable in urban environments, where pedestrian activity is highest and vehicular traffic is most intense.

Overall, the research results confirm that pedestrians represent the most vulnerable group of road users in urban traffic in Serbia. The particularly high number of casualties during winter months and the concentration of accidents in urban areas emphasize the need for systemic measures that enhance pedestrian safety while simultaneously promoting sustainable mobility. Key aspects include improving pedestrian visibility, upgrading urban infrastructure (lighting, crosswalks, sidewalks), and implementing effective speed control in areas with high pedestrian traffic, directly contributing to safer and more sustainable movement in urban environments.

1.2. Attitudes Toward Walking

The results indicate a strong awareness among respondents of the health, environmental, and economic benefits of walking, alongside clear challenges regarding infrastructure and safety in the Republic of Serbia. Figure 2 presents the results of the survey.

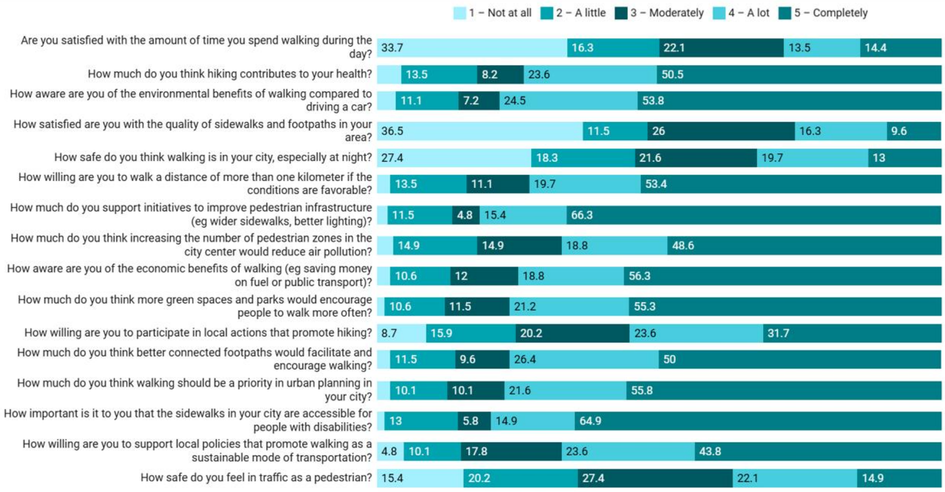

Figure 3. Survey results on public attitudes toward walking in the Republic of Serbia

The majority of respondents (33.7%) believe that they do not spend enough time walking, while only 14.4% are completely satisfied, indicating a gap between desired and actual habits. Furthermore, the perception of the health benefits of walking is very high—50.5% of respondents believe it significantly contributes to health, and an additional 23.6% recognize this to a lesser extent. On the other hand, the quality of pedestrian infrastructure represents a significant issue, as 36.5% of respondents expressed dissatisfaction with sidewalks and walking paths, while only 9.6% were completely satisfied. A particular challenge is the sense of safety, especially at night—27.4% feel unsafe, and 21.6% report moderate concerns, highlighting the need for improved lighting and safer urban solutions.

Conversely, the results also show a strong willingness among citizens to support measures to improve pedestrian conditions: 66.3% of respondents strongly support initiatives such as expanding sidewalks and improving lighting, while 48.6% believe that increasing pedestrian zones can be an effective solution to reduce pollution. High awareness of economic benefits is also evident, as 56.3% of respondents recognize fuel and public transport savings as an important incentive for walking. Additionally, 64.9% emphasize the importance of sidewalk accessibility for persons with disabilities, confirming growing awareness of inclusive urban planning. Finally, more than half of respondents (55.8%) believe that walking should be a priority in urban planning, clearly indicating a general opinion that cities should become more pedestrian-friendly, safer, and sustainable.

DISCUSSION AND CONCLUSION

The results indicate the complexity of pedestrian safety issues while confirming the significance of walking as a sustainable mode of mobility in urban areas. Analysis of pedestrian casualties shows that during the period 2022–2024, 370 pedestrians were fatally injured in the Republic of Serbia, while nearly 8,000 people were injured, clearly positioning pedestrians as one of the most vulnerable categories of road users. It is particularly concerning that the majority of accidents occur in urban areas, with over 95% of all casualties recorded there, confirming previous research findings (Pljakić et al., 2025) that urban spaces pose higher risks to pedestrians due to the combination of intense traffic and high pedestrian volumes.

Seasonal fluctuations in the number of fatalities and injuries further highlight the importance of adapting safety measures to weather conditions. The highest number of casualties was recorded during winter months and transitional periods, when visibility and road conditions are impaired. These findings point to the need for targeted measures, such as improved public lighting, road maintenance, and enhanced speed control during periods of increased risk.

In the second part of the study, the survey results provide valuable insight into citizens' perceptions and attitudes toward walking. Despite high awareness of the health, environmental, and economic benefits, numerous challenges related to infrastructure quality and the sense of personal safety are evident. Dissatisfaction with sidewalks and insufficient safety in pedestrian areas, particularly at night, represent key barriers to increased walking. These findings align with global research indicating that the quality of pedestrian infrastructure and subjective safety perceptions directly influence citizens' willingness to choose walking as a daily mode of transport.

It is important to note that citizens demonstrate a willingness to support systemic changes—from improving walking paths and lighting to increasing pedestrian zones and adapting spaces for persons with disabilities. Such public orientation provides a significant basis for policies that promote sustainable mobility and a safer urban environment.

By combining the findings of both analyses, it can be concluded that pedestrian issues in Serbia must be addressed from two perspectives: safety and development. On one hand, it is necessary to reduce the risk of casualties through infrastructural improvements and traffic management, while on the other hand, there is a clear societal potential to promote walking as a desirable mode of transport. This approach would simultaneously enhance safety, public health, and the quality of urban life.

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Sizing and preliminary calculation of an electric drive unit for electrification and tuning of a city bus

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ABSTRACT

The article discusses issues related to the preliminary selection and calculation of an electric traction unit for the electrification and tuning of a city bus. Methodological approaches to determining the required power and torque of an electric motor are presented, taking into account the operating conditions of the urban traffic cycle, the mass of the vehicle, and its dynamic characteristics. A comparative analysis of various types of traction electric motors (asynchronous, synchronous with permanent magnets, and commutator) is performed in terms of energy efficiency, dimensional and weight characteristics, and cost. The criteria for selecting a battery and control system to ensure an optimal balance between range, energy consumption, and reliability are justified. The results of preliminary calculations show the promise of using a synchronous electric motor with permanent magnets for the modernization of buses in urban conditions. The proposed approach can be used in the development of public transport electrification projects, as well as in engineering work on the conversion and tuning of existing buses.

Keywords: transport electrification, city bus, electric traction unit; preliminary calculation, electric motor selection, synchronous motor with permanent magnets, battery, control system, energy efficiency, bus tuning.

INTRODUCTION

The development of electric transport is one of the key trends in the modern automotive industry and urban transport infrastructure. The transition from traditional buses with internal combustion diesel engines to electric models is driven by the need to reduce harmful emissions, lower noise levels, and improve energy efficiency in densely populated urban areas. According to global forecasts, by 2030, electric buses will account for more than half of all public transport vehicles in major metropolitan areas. [1]

BASICS OF SIZING AND CALCULATION OF ELECTRIC DRIVE FOR A BUS

The subject of the study, which is a tunable or electric bus, was a Mercedes Benz city bus. We will conduct the requisite calculations for selecting an electric drive for the conversion and electrification of the bus into an electric bus.

Table 1 presents the essential technical characteristics required for the calculation and initial selection of an electric drive for an electric bus.

Table 1. Calculation of electric motor power for the "Mercedes Benz" bus

Parameter		Value
Donor bus's equipped mass 10900 kg.		9600
Weight of one battery 100Ah constitutes 3,6 кg. Set of 2050 batteries weighs 7380 кg.		7380
Electric motor weight 30 kW - 200 kg.		200
Controller weight 30кW -30 kg.		30
Additional weight (transition plate, wires, fastening, charger, radiator fluid)		100
Total mass with rounding 17310 kg.		17310
We add the mass of the driver and passengers, 94 people * 85 kg.		8000
Additional useful weight (passenger, baggage)		550
Finally, we accept the total calculated mass 25860 kg.	m	25860
We are given the values of the coefficients:		
C_x=0,342 (Aerodynamic drag coefficient);	Cx	0,342
S=5 m^2 (car's cross-sectional area);	S	5
g = 9.8 m/s^2 (acceleration due to gravity);	g	9,8
F_{fr}= 0,018 (friction force coefficient for asphalt);	Fтр	0,018
V vehicle speed in km/h	V	120
V is the speed of the car in m/s - we convert the speed from km/h to m/s by	V	33,3

dividing by 3.6.		
α= 0° (road inclination angle);	α	0
ρ_{air}=1,225 кg/m^3(air density).	$\rho_в$	1,225

$$W=gF_{fr}mV\cos\alpha+0,5C_xS\rho_{air}V^3+gm\sin\alpha V$$

$$M_{gen}. \text{ auto} =9600+7380+200+30+100=17310 \text{ (kg)}$$

Accepting the full calculated mass of the electric bus:

$$M_{Passengers} = 26+68=94 \text{ (person)} * 6 \text{ (kg. cargo)} = 550 \text{ (kg)}$$

$$M_{auto\ calcul}= 17310+8000+550= 25860 \text{ (kg)}$$

$$W=9,8*0,18*25860*33,3*\cos(0*3,14/180)+0,5*0,342*5*1,225*33,33+9,8*25860*$$

$$*\sin (0*3,14/180)*33,3=190848 \text{ (W)}= 191 \text{ (кW)}$$

$$H_{gen}=1*0,9*0,95=85,5\%$$

The power of the electric motor, considering the total efficiency is equal to:

$$W_{calcul} =190848/85*100=223215 \text{ (W)} = 223 \text{ (кW)}$$

Design power of an electric motor = 190848 (W) = 191 (кW)

Efficiency (transmission (~1), electric motor (~0.90), controller (~0.95)) = 85.5%

The calculated power of the electric motor, taking into account the efficiency = 223215 (W) = 223 (kW) = 302 (hp)

$$A=gF_{fr}m_{complete} =9,8*0,018*25860=4562$$

$$B=0,5C_xS\ \rho_{air}=0,5*0,342*5*10225=1,047$$

$$C= gm_{complete}=9,8*250860=253428$$

$$\text{angle} = \text{arctg}(0,01*\text{slope } \%).$$

RESULTS OF SELECTION AND CALCULATION OF BUS ELECTRIC DRIVE

The results of the power-velocity dependence are presented in Figure 1.

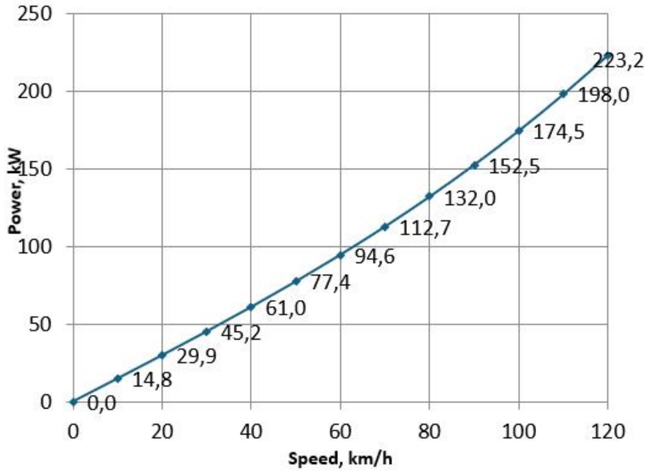

Figure. 1. Power-to-speed dependence

Figure 2 shows the dependence of the power on the angle of inclination of the road surface.

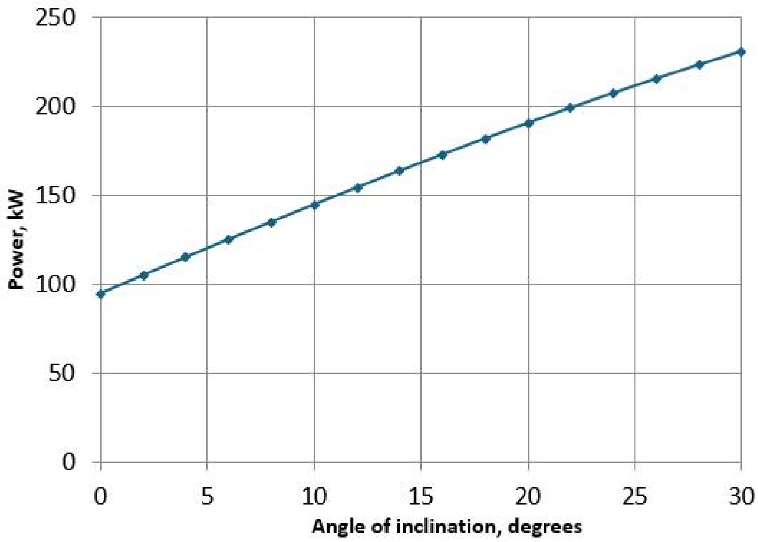

Figure 2. Power dependence on the angle of inclination

RELIABILITY OF THE RESULTS OBTAINED

$$W_{Battery} = A/t = 651043\ (J)/2{,}9\ (h) = 225\ кW$$

Table 2. Calculation results of unit parameters "Mercedes Benz" electric bus.

Parameter	Value	Note
Distance, km	350	distance, km
Battery voltage, V	480	voltage battery, V
Consumed power, W	223215	Calculated
Average speed, km/h	120	Calculated

Movement time, h	2,9	energy
Consumed energy, J	651043	energy
Consumed energy, кW	225	кW
Minimum battery capacity, Ah	13564	Ah (calculation)
Battery recoil current, A	4050	Ampere (calculation)
Weight LiFePO4 АКБ, kg	7324	kg
Charging time LiFePO4 battery, h	387,5	min (35A fast charging)

CONCLUSION

The research investigated aspects concerning the sizing and preliminary computation of an electric traction unit for the electrification and adjustment of a city bus. The accurate identification of the necessary parameters of the electric motor—power, torque, and operational speed range—is crucial for ensuring the vehicle satisfies the operational demands of the urban traffic cycle.

The results gained validate the potential of a systematic method for the electrification of urban buses, which enhances both environmental and economic performance while enabling the upgrading of the current fleet without necessitating total replacement. The suggested approach for initial computation of the electric traction unit is applicable during the engineering design phase and in the execution of conversion projects within public transportation.

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The transition to electric bus transportation: a step towards a sustainable future

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ABSTRACT

This article evaluates the transition from buses running on various types of fuel to electric buses as an important step toward achieving sustainability. As concerns over urban air pollution and greenhouse gas emissions continue to grow globally, electric buses are increasingly seen as a clean, energy-efficient, and sustainable solution for public transportation systems. The article analyzes the social, environmental, and economic impacts of introducing electric buses in the city of Tashkent and outlines existing challenges and practical recommendations for achieving a sustainable future.

Keywords: Urban mobility, Low-emission vehicles, Electric buses, Environmental safety of transport, Transport emissions, Energy-efficient transport, Climate change.

INTRODUCTION

The growing processes of globalization and integration occurring around the world are leading to the expansion of passenger and freight transportation links between countries. On the one hand, this process demands the comprehensive development of transport systems and the creation of new, affordable, and fast routes. On the other hand, it requires the coordination of transportation systems that connect regional countries with global transport networks.

In recent years, issues such as global climate change, air pollution, resource efficiency, and energy effectiveness have become pressing topics on the global agenda. Especially in large cities, the contribution of transportation systems to air pollution is significantly high. According to the *State of Global Air 2024* report, air pollution caused 8.1 million deaths worldwide, with a major share occurring in large urban centers [1].

According to the International Energy Agency, the transport sector is a major contributor to global greenhouse gas emissions, accounting for approximately one-quarter of direct CO_2 emissions resulting from fuel combustion [2]. Traditionally, public buses that run on non-renewable fuel sources make a significant contribution to urban air pollution. As cities strive to reduce their carbon emissions, the transition to electric buses emerges as a viable and necessary alternative.

The sustainability and development of the transport system are of great importance for the Republic of Uzbekistan, as it provides essential conditions for societal activity alongside other infrastructure sectors, and serves as a crucial element in achieving socio-economic and socio-environmental goals. The historical development of the transport system plays a defining role in Uzbekistan's path to sustainability and supports its integrity and international influence. Transitioning the urban public transport system to an environmentally friendly and sustainable model including the adoption of low-emission buses is seen as a solution to this issue.

Studying the integration of sustainable transport elements as a system, identifying existing problems in organizing it efficiently, determining the influencing factors, and developing scientifically based proposals to improve the management effectiveness of the public transport system along with their practical implementation highlight the relevance of this research topic.

In Uzbekistan, large-scale reforms based on the principles of “green transport” and environmental sustainability are also being implemented in the transport sector. According to Presidential Decree No. PQ–59 dated February 16, 2023, improving urban ecology, updating the vehicle fleet with modern and eco-friendly buses, and modernizing public transport are identified as key priorities [3].

In recent years, a diverse fleet of buses has been operating in Tashkent, some of which run on electric power. The rest operate on diesel and compressed natural gas, which result in significant CO_2 emissions. According to data from the Ministry of Transport of the Republic of Uzbekistan and “Toshshahartransxizmat” JSC, as a result of measures aimed at accelerating the introduction of low-emission vehicles into Tashkent’s public transport system, the volume of harmful substances emitted by operating vehicles decreased from 5.1 thousand tons in 2022 to 4.8 thousand tons in 2023 [4]. The geographical and environmental conditions of Tashkent are also of particular importance. Because the city is located on a plain with limited air circulation, harmful gases tend to linger in the atmosphere for long periods. This creates serious problems not only from an environmental standpoint but also in terms of public health and economic efficiency.

Furthermore, electric buses are not only environmentally friendly but also offer long-term economic advantages. They require less maintenance, have lower fuel costs, and provide users with quiet, smooth, and high-quality transport services.

For these reasons, this study focuses on the transition to electric bus transportation in the city of Tashkent, with special attention to its environmental benefits and economic efficiency.

RESEARCH METHODOLOGY

In order to organize and manage the public transportation system in Tashkent effectively, and to address issues of socio-environmental safety within this process, the study analyzes the key emission indicators of the city's bus transport. Through methods of analysis and synthesis, the study presents directions for the development of their operations.

Factors impacting the environment include emissions that affect urban air quality and human health - namely greenhouse gases and air pollutants. Greenhouse gases, particularly CO_2, contribute to climate change and are considered one of its main drivers. Motor vehicles are among the primary sources of these emissions. Additionally, due to incomplete combustion of fuel in vehicles, various pollutants are emitted into the air. These include carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), and volatile organic compounds (VOC). These emissions can result in smog, cardiovascular and respiratory diseases, and even cancer.

The identification of CO (carbon monoxide) and CO_2 (carbon dioxide) emissions is directly linked to their sources - specifically fuel combustion. In calculating these harmful gases, CO is mainly formed as a result of incomplete combustion, and is typically measured under laboratory conditions using empirical methods. Likewise, HC (hydrocarbons) and NO_x emissions are calculated based on emission coefficients and activity levels. These are determined by factors such as fuel consumption, distance traveled, type of transport, vehicle age, and compliance with Euro emission standards.

Since complete combustion of fuel in vehicle engines produces carbon dioxide (CO_2), the amount of CO_2 emissions is calculated based on fuel consumption. The methodology for calculating CO_2 emissions is explained as follows:

1. The emissions are determined according to the type of vehicle and the fuel it consumes (e.g., passenger cars, freight vehicles, buses, and special-purpose vehicles);

2. The total volume of CO_2 emissions is calculated based on the amount of fuel consumed and the emission factor for each type of fuel and vehicle.

The formula for calculating CO_2 emissions is as follows [5]:

$$E = M \times K_1 \times TNZ \times K_2 \times 44/12 \tag{1}$$

Where,

- E – CO_2 emissions (tons);
- M – Actual fuel consumption (tons);
- K_1 – Carbon oxidation coefficient;
- TNZ – Calorific value of the fuel (Joules/ton);
- K_2 – Carbon emission factor (tons of C / Joule);
- 44/12 – Conversion factor from carbon to CO_2 (based on molar mass).

Note: It can be understood that for every 12 grams of carbon burned, 44 grams of CO_2 are produced.

In calculating greenhouse gas emissions, the calorific value of the recommended fuel and the carbon emission factors (in CO_2 equivalent) are presented in **Table 1**.

It is worth emphasizing that the use of any type of vehicle is closely linked to its environmental impact, that is, its ecological indicators. In this context, the increase in the amount of harmful exhaust gases released into the atmosphere is assessed based on standard levels of environmental pollution.

Table 1. Calorific values and Carbon emission factors

Fuel type	Net Calorific Value, lower (TJ/1000 tons)	Carbon Emission Factor (K2, tC/TJ)	Oxidized Carbon Fraction (K1)
Gasoline	44.21	19.13	0.995
Diesel	43.02	19.98	0.995
Liquefied Gas	47.17	17.91	0.990
Compressed Natural Gas	34.78	15.04	0.995

ANALYSIS AND RESULTS

Conducting research on the current state of the transport system, as well as analyzing its development prospects and trends, directly influences long-term strategies and current transport policies. It also serves as a foundation for identifying financial needs, workforce requirements, and material-technical resources, as well as for developing a comprehensive transport development plan.

A sustainable transport system is considered the lifeblood of Tashkent's urban economy. Therefore, the development of the transport system must be aligned with the needs of the city’s economy. Otherwise, problems within the transport system may negatively affect the overall growth of the urban economy.

Ensuring the sustainability of urban public transportation primarily implies maximizing the use of available vehicles, achieving cost-efficiency, calculating economic performance indicators, and maintaining the profitability of the transport organization. However, it is difficult to adequately assess the sustainability of the urban transport system using a single indicator. For this reason, multi-criteria approaches are currently employed.

A range of quality indicators that reflect transport services collectively form a general efficiency criterion, allowing for an objective evaluation of the public transport system's performance. In general, the sustainability of the urban transport system may include technical-economic, socio-environmental, and organizational-technical indicators.

Despite developments in Tashkent’s transport system in recent years, it still faces several serious challenges. The most prominent issues include:

- A sharp increase in the number of private vehicles, which has grown by an average of 15–20% over the past two years;
- A significant rise in traffic congestion during peak hours on central city roads (reaching levels of 8–10 on the Yandex Traffic scale);
- Transport infrastructure that fails to meet modern standards, including a shortage of parking facilities and road signs;

- Inefficient operation of traffic management systems, along with an increase in the volume of harmful exhaust gases emitted into the atmosphere;
- Poorly organized public transport services, and other related shortcomings.

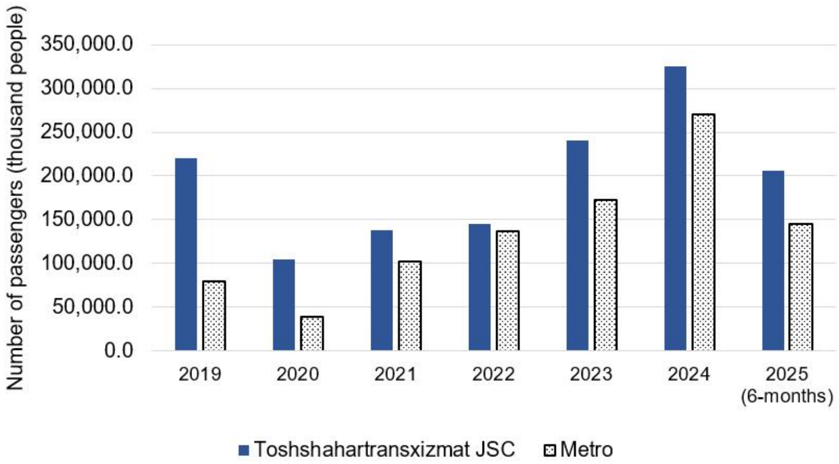

Figure 1. Number of public transport passengers in Tashkent

This study was conducted using data provided by **"Toshshahartansxizmat" JSC**. **Table 2** presents the most commonly used types of buses currently operating in the city of Tashkent. For the years **2020–2025**, average daily operational indicators from **eight bus depot branches** under "Toshshahartansxizmat" JSC are presented in **Table 2**. This table includes key performance metrics of route buses operating under "Toshshahartansxizmat" across its eight bus depot branches, averaged over daily operations from 2020 to 2025.

Table 2. Most common bus types in Tashkent

№	Bus type	Fuel type	Units	Fuel consumption (/100 km)
1	Yutong ZK6126BEVG	Electric	kW h	93
2	MAN A22	Compressed Natural Gas	m^3	79
3	*Yutong ZK6126HG*			74
4	King Long XMQ6180G			96
5	SAZ LE-60	Diezel	Liter	32
6	Mercedes Benz O345 Conecto Low floor			49,4

Table 2. Operational performance indicators of route buses

Year	Number of routes	Number of Buses			Number of Trips			Average distance of routes (km)
		Working days	Saturday	*Sunday*	Working days	Saturday	Sunday	
2020	129	1,079	982	912	15,860	13,695	12,687	2,797.52
2021	142	1,120	1,016	927	16,650	14,544	13,134	2,657.84
2022	153	1,068	941	841	16,218	13,835	12,070	2,724.11
2023	164	1,656	1,455	1,292	25,147	21,000	18,495	2,956.47
2024	164	1,566	1,394	1,244	22,930	19,657	17,386	2,989.28
2025	164	1,566	1,400	1,254	20,396	17,866	16,260	2,981.90

In this study, the total specific fuel consumption of all buses was calculated based on their daily travel distance, taking into account real-world operating conditions. The fuel consumption of buses was analyzed according to their use of compressed natural gas (CNG), diesel fuel, and electric energy.

To calculate specific fuel consumption, the recommended fuel consumption rates under average normal weather conditions were used, based on the average fuel (or energy) consumption per 100 kilometers for each type of vehicle. For greenhouse gas (GHG) emissions, the recommended methodology based on fuel type and the calorific value of carbon emissions was applied.

The calculations were made considering both the total number of buses in daily operation and their average travel distance. According to data from Toshshahartansxizmat JSC as of July 16, 2025, the total daily mileage of 164 route buses exceeds 395,000 kilometers (see Table 3).

Through statistical analysis, the daily distribution of buses in Tashkent by fuel type reveals the following:

Diesel-powered buses account for 21% of the total daily travel distance;

Compressed natural gas (CNG) buses account for 62%;

Electric buses make up 17%.

Table 3. Average travel distance and Fuel consumption of buses

№	*Bus type*	Fuel type	Units	Average daily travel distance (km)	Daily fuel consumption
1	Yutong ZK6126BEVG	Electric	kW h	71,781.50	66,756.80
2	MAN A22	Compressed Natural Gas	m^3	58,150.95	45,939.25
3	Yutong ZK6126HG			116,594.12	86,279.65
4	King Long XMQ6180G			65,688.55	63,061.01
5	SAZ LE-60	Diezel	Litr	62,726.035	20,072.33
6	Mercedes Benz O345 Conecto Low floor			20,392.265	10,073.78
			Totals:	395,333.42	

Based on this analysis, diesel and gas-powered buses collectively account for 83% of the total vehicle-kilometers traveled, indicating a significant environmental burden caused by these types of transport.

According to daily data on buses operating in Tashkent, the total CO_2 emissions exceed 377,000 tons (see Table 4). On an annual basis, this figure reaches approximately 113.123 million tons.

In recent years, large-scale reforms have been implemented in the public transport system of Tashkent. These reforms aim to provide the city's residents with convenient, safe, and high-quality transportation services, while also promoting the widespread adoption of modern technologies and environmentally friendly, sustainable transport solutions.

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Table 4. Daily CO_2 Emissions released into the Environment

№	Bus type	Fuel type	Units	Daily fuel consumption	Daily amount of CO_2 (tons)	*Annual amount of CO_2 (million tons)*
1	Yutong ZK6126BEVG	Electric	1000 kWh	66.8	-	-
2	MAN A22	Compressed Natural Gas	Tons (м^3×0.0008)	36.75	70,137	21,041
3	Yutong ZK6126HG			69.02	131,726	39,518
4	King Long XMQ6180G			50.45	96,277	28,883
5	SAZ LE-60	Diezel	Tons (0.835 kg/litr)	16.76	52,559	15,768
6	Mercedes Benz O345 Conecto Low floor			8.41	26,378	7,913
				Totals:	377,077	113,123

Currently, 322 electric buses are in operation in Tashkent, and an additional 200 electric buses are expected to be added in the near future. This will bring the total number of electric buses to 522 units.

This expansion is aimed not only at ensuring environmental cleanliness, but also at modernizing the bus fleet and improving overall service standards.

In this study, forecast indicators for reducing air pollution through an increase in the number of electric buses are presented in Table 5. Currently, the share of electric buses in the public transport system is approximately 20%. If this share increases to 33% in the coming years, the forecast suggests that the volume of harmful emissions could decrease by up to 18.19 million tons per year.

Additionally, electric buses typically have lower maintenance costs compared to traditional buses, which could contribute to a reduction in overall operational expenses.

Table 5. Forecast of CO_2 Emission Reduction

Years	Percentage of electric buses	CO_2 emissions (million tons)
2024-2025	20%	113,123
2025-2026	33%	94,936

The electricity consumption costs of 322 "YUTONG ZK6126 BEVG" electric buses, owned by Toshshahartansxizmat JSC, have been analyzed based on the actual distance traveled. This analysis includes a comparative assessment of the same travel distance using equivalent vehicles powered by compressed natural gas (CNG) or diesel fuel. The results of this comparison are presented in Table 6.

Table-6. Comparative result of expenses spent on fuel

№	Bus type	Distance traveled (km)	Energy source	Units	Energy consumption	Cost of consumed energy (thousand UZB soums)
1	YUTONG ZK6126 BEVG	29,665,857	Electric	kW	27,061,737	16,894,159.0
2	YUTONG ZK6126 HG	29,665,857	Compressed Natural Gas	m^3	20,884,763.33	69,963,957.2
3	Mercedes Benz O345 Conecto Low floor	29,665,857	Diezel	Liter	14,654,933.36	158,352,768.6

CONCLUSION AND RECOMMENDATIONS

The research results reveal the necessity and feasibility of implementing a low-emission bus system, using the example of Tashkent city. Analysis of statistical data shows that increasing the annual share of electric buses from 20% to 33% could reduce carbon dioxide (CO_2) emissions from 113.1 million tons to 94.9 million tons per year. This would significantly reduce the negative impact on the environment and help improve the city's ecological sustainability.

Based on scientifically grounded forecasts, it is possible to propose implementing this system in other cities of the Republic as well. Moreover, the Tashkent city experience will allow for testing the main efficiency and safety of electric buses, and understanding how they perform within public transportation networks. A well-organized pilot program is crucial to obtain initial results and determine strategies for expansion.

The experience in Tashkent demonstrates that transitioning to electric bus transport is a step toward a sustainable future, and implementing it in other regional centers would be appropriate. It is evident that developing a charging infrastructure and establishing technical service centers will be necessary.

For Uzbekistan's regions and cities to fully transition to electric transport, it will require the development of all necessary infrastructure and services to support it. As a result, social and economic efficiency would increase, and through scientific research, sustainability could be ensured improving the ecological stability of the transport system, reducing fuel imports and operational costs, and creating healthier living conditions for the population.

In conclusion, the gradual implementation of this system represents a significant step for Uzbekistan toward environmental sustainability, economic efficiency, and technological innovation. It will contribute to substantial changes in the country's transportation system, enhance living conditions for the population, and improve environmental impact. While challenges may exist, the long-term benefits in terms of sustainability, public health, and economic growth are considerable.

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The impact of parking cars in urban conditions on traffic volume and composition

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ABSTRACT

This article analyzes the impact of car parking conditions in urban areas on the volume and composition of traffic flow, using the example of parking zones in Jizzakh city. The study examines the density of traffic flow, the composition of vehicles (passenger cars, trucks, public transport), and the influence of parking spaces on road traffic. Additionally, systemic solutions are proposed to improve the traffic volume and composition in urban parking conditions.

Keywords: traffic intensity, vehicle composition, distribution curve, cumulative frequency, congestion, parking.

INTRODUCTION

The efficiency of the urban transport system depends on numerous factors, one of the most significant being the process of parking vehicles. The irregular parking of cars on city streets directly impacts road traffic, leading to reduced traffic flow intensity and disrupted flow dynamics due to the uneven distribution of vehicle types. Furthermore, it contributes to an increase in harmful gas emissions from vehicles, which, in turn, has a serious impact on the environment and ecology. The parking system in urban conditions should be considered not only as a matter of placement but also as a transport management factor ensuring traffic stability.

Changes in traffic volume and composition affect traffic speed and the occurrence of road accidents. Frequent fluctuations in traffic volume and its composition are observed on the lanes of city streets. Currently, an increasing level of motorization can be observed worldwide. The motorization level in Russia alone can be seen from the data presented in Table 1 [1].

Table 1. Changes in the Motorization Level of the Russian Population

Growth rate	1991	1994	1999	2005	2020
Motorization rate, passenger cars per 1,000 people	80	100	140	170	300
Number of cars per family, piece	0,25	0,33	0,4	0,5	1

Certainly, this trend is observable not only in a single country but also globally, as motorization levels continue to rise worldwide. This leads to an increased demand for parking spaces. Currently, this has become a significant problem. As a result, parking spaces for vehicles are being created on the roadway itself. It is evident that this situation negatively impacts vehicle movement, particularly complicating the operation of public transport, reducing the road's capacity, causing traffic congestion, and decreasing vehicle speeds.

To study the impact of parking vehicles on traffic volume and composition in urban conditions, the parking area near the Central Farmers' Market in front of Temiryolchilar Street in Jizzakh city was selected [3-5].

The condition of the road on the streets, along with traffic intensity, is an indicator that shows the variation in the speed of different types of vehicles across road lanes, both individually and collectively, i.e., the speed of the traffic flow, which can be studied separately. Collecting data on speed begins with determining instantaneous speed. The initial data obtained on traffic speed are analyzed using mathematical statistics methods, and distribution curves and cumulative frequency graphs are constructed. From the distribution curve, the modal speed is determined, while the cumulative frequency graph identifies the speeds corresponding to 15%, 50%, 85%, and 95% assurance levels [2].

Research was conducted at distances of 50 and 100 meters from the entry and exit points of the parking area in front of the Central Farmers' Market on Temiryolchilar Street in Jizzakh city.

Table 2. Calculation of observation tasks using statistical methods

№	Categorizing, km/h	Repetition, unit		Frequency, %		Collected frequency, %	
		Entering	Exiting	Entering	Exiting	Entering	Exiting
1	15-20	1	72	0.8	60	0.8	60
2	20-25	19	37	15.8	30.8	16.7	90.8
3	25-30	76	11	63.3	9.2	80	100
4	30-35	21	0	17.5	0	97.5	100
5	35-40	2	0	1.7	0	99.2	100
6	40-45	1	0	0.8	0	100	100
7	45-50	0	0	0	0	100	100
8	Total:	120	120	100.0	100.0		

Figure 1 presents the distribution curve graph at a distance of 50 meters from the entry and exit points of the parking area. According to it, the modal speed at the entrance to the parking area is 25–30 km/h. The modal speed at the exit from the parking area is 15–20 km/h.

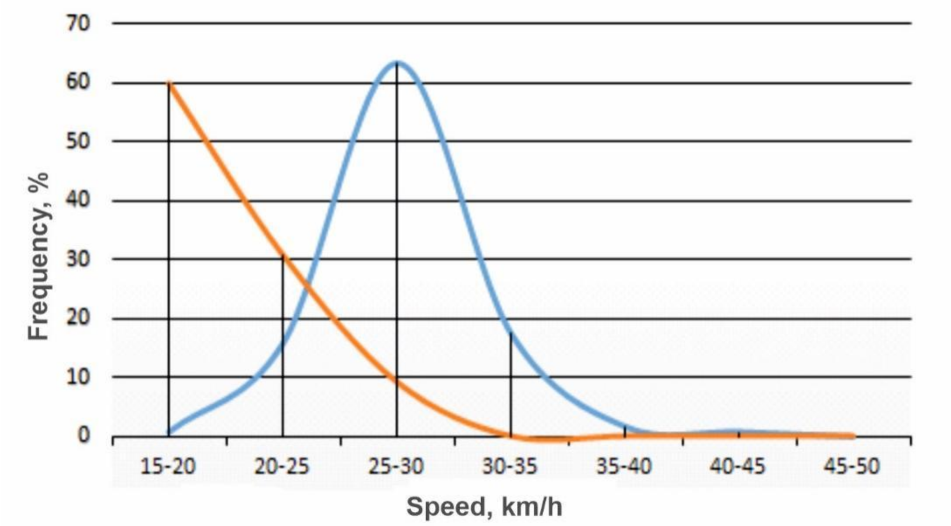

Figure 1. Distribution curve graph;1-Enter parking lot; 2-Exit parking lot.

Figure 2 presents the cumulative frequency graph at a distance of 50 meters from the entry and exit points of the parking area. According to it, the speed corresponding to 95% assurance is considered the design speed and is used in the calculation of road elements. The assured speed at the entrance to the parking area is $V_{95\%} = 31$ km/h, while the assured speed at the exit from the parking area is $V_{95\%} = 24$ km/h.

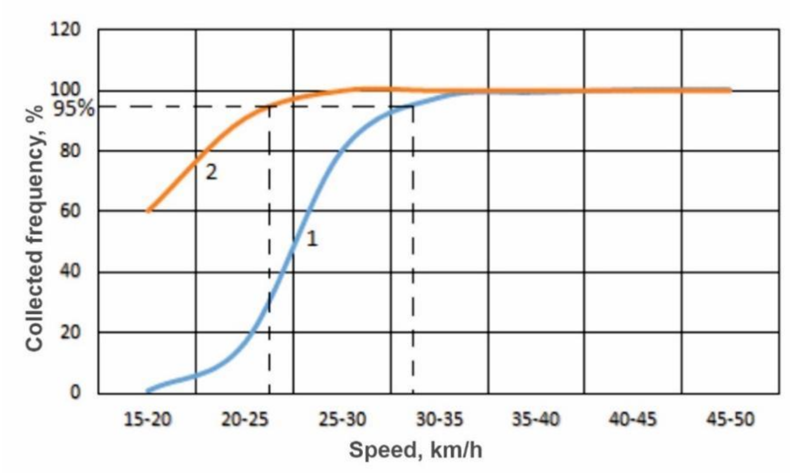

Figure 2. Cumulative curve graph. 1-Enter parking lot; 2-Exit parking lot.

Figure 3 presents the distribution curve graph at a distance of 100 meters from the entry and exit points of the parking area. According to it, the modal speed at the entrance to the parking area is 30–35 km/h. The modal speed at the exit from the parking area is 15–20 km/h.

Table 3. Calculating observation tasks using a statistical method

№	Categorizing, km/h	Repetition, unit		Frequency, %		Collected frequency, %	
		Entering	Exiting	Entering	Exiting	Entering	Exiting
1	15-20	4	64	3.3	53.3	3.3	53.3
2	20-25	15	41	12.5	34.2	15.8	87.5
3	25-30	28	12	23.3	10	39.1	97.5
4	30-35	37	3	30.8	2.5	70.0	100.0
5	35-40	23	0	19.2	0	89.1	100.0
6	40-45	12	0	10	0	99.1	100.0
7	45-50	1	0	0.8	0	100.0	100.0
8	Total:	120	120	100.0	100.0		

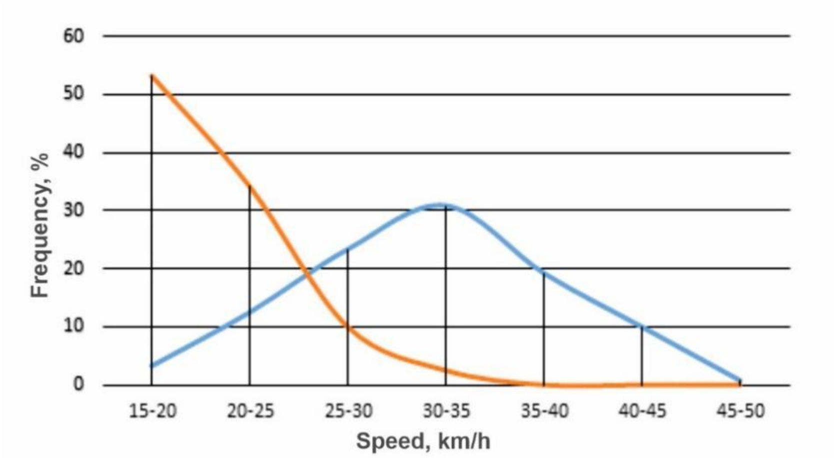

Figure 3. Distribution curve graph. 1-Enter parking lot; 2-Exit parking lot.

Figure 4 presents the cumulative frequency graph at a distance of 100 meters from the entry and exit points of the parking area. According to it, the speed corresponding to 95% assurance is considered the design speed and is used in the calculation of road elements. The assured speed at the entrance to the parking area is $V_{95\%} = 40$ km/h, while the assured speed at the exit from the parking area is $V_{95\%} = 25$ km/h.

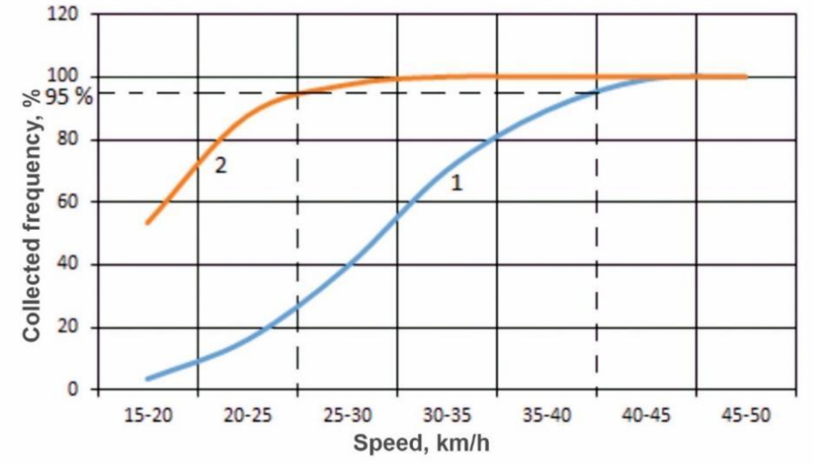

Figure 4. Cumulative curve graph. 1-Enter parking lot; 2-Exit parking lot.

The results of observations conducted to determine speed primarily depend on the number of measurements taken. The accuracy probability of the indicators is tied to the number of measurements, which, in turn, is related to changes in traffic volume.

Figure 5 presents a graph of the assured speeds determined at specified distances from the entry and exit points of the parking area.

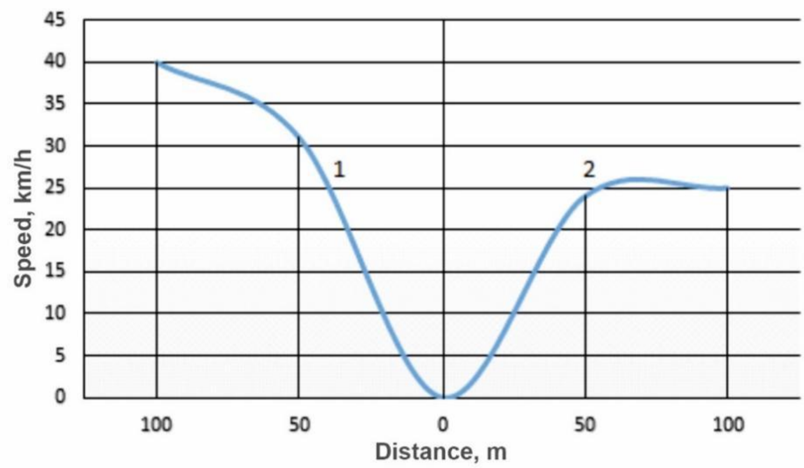

Figure 5. Speed graph based on distances from the enter and exit of the parking area. 1-Enter parking lot; 2-Exit parking lot.

CONCLUSION AND RECOMMENDATIONS

Parking vehicles in urban conditions directly and indirectly impacts the volume and composition of traffic flow. Improper parking reduces the efficiency of the transport system, contributes to increased traffic congestion, and affects traffic safety.

When planning parking spaces, traffic composition, flow dynamics, and urban infrastructure should be considered together. Based on the research conducted on Temiryolchilar Street in Jizzakh city, the following conclusions can be drawn:

- A critical speed limit should be established on the aforementioned street, particularly in areas near markets;
- Temporary stopping of vehicles along the edge of the roadway should be prohibited on high-intensity two-lane streets;
- Based on the provided data, the capacity of parking areas on this street, especially near the Central Farmers' Market, is insufficient, necessitating the construction of a large-capacity multi-level parking facility;
- Implement efficient smart parking systems in the city’s central streets;
- Introduce artificial intelligence systems to regulate traffic flow;
- Prioritize public transport and bicycle lanes.

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Comparison of ECMS and rule-based control methods for REEV

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ABSTRACT

Development of efficient control strategies play an important role in the performance optimization of Range extended electric vehicles (REEV). The optimized energy consumption minimization control strategy (ECMS) is developed to improve energy efficiency of REEVs. The simulation results obtained using the proposed ECMS are compared with those of the existing Rule-based control strategy. The simulation results showed that fuel consumption was reduced by around 5% for both the UDDS and HWFET driving cycles.

Keywords: REEV, rule – based, ECMS, auxiliary power unit

INTRODUCTION

New energy vehicles offer a more attractive solution for reducing emissions and conserving fossil fuel resources. Range extended electrical vehicles (REEV) are one type of new energy vehicles due to their electrified propulsion and reduced consumption of fossil fuels. REEVs use an electric battery and an internal combustion engine together with a generator as their primary and auxiliary power units (APU). The engine connected to generator is decoupled from the wheels, which allows for simpler control strategies compared to other hybrid electric vehicles [1].

The main goal of the control strategy is to distribute required power optimally between the battery and the APU, thereby enhancing fuel efficiency and reducing emissions [1]. To achieve these objectives, various control strategies have been proposed and developed over the years. Control strategies are commonly classified as rule-based or optimization-based methods [2]. Jeong and etc. [3] developed a rule-based algorithm for a REEV model that taking into account thermal conditions. Wu and etc. [4] investigated a novel multi objective energy management strategy (EMS) in order to reduce battery degradation and avoid frequent engine start -stop by introducing power follower EMS and traditional adaptive ECMS for REEVs. Jeong and etc. [5] developed a dynamic programming algorithm for developing series HEV model. By applying this algorithm, calculation time is reduced significantly.

The fundamental principle of EMSs applied to REEV is to operate the internal combustion engine (ICE) within its most efficient region, due to the fact that the engine is not directly connected to the drivetrain [6]. This paper presents an ECMS based control method that aims to operate the engine along its minimum fuel consumption line to maximize efficiency. A comparative analysis is conducted between the proposed and existing rule-based control strategies to evaluate the performance of the proposed strategy.

POWERTRAIN STRUCTURE OF REEV

The main components of a REEV include the transmission, electric motor, battery and an auxiliary power unit (APU) which comprises an engine coupled with generator, as illustrated in Figure 1. The propulsion power is provided by the electric motor, that draws energy from either the battery, the APU, or both depending on the control strategy.

$$P_{req} = P_{batt} + P_{APU} \quad (1)$$

Where P_{req} - required power for propulsion, $[W]$; P_{batt} - output power of battery, $[W]$; P_{APU} – output power of APU, $[W]$;

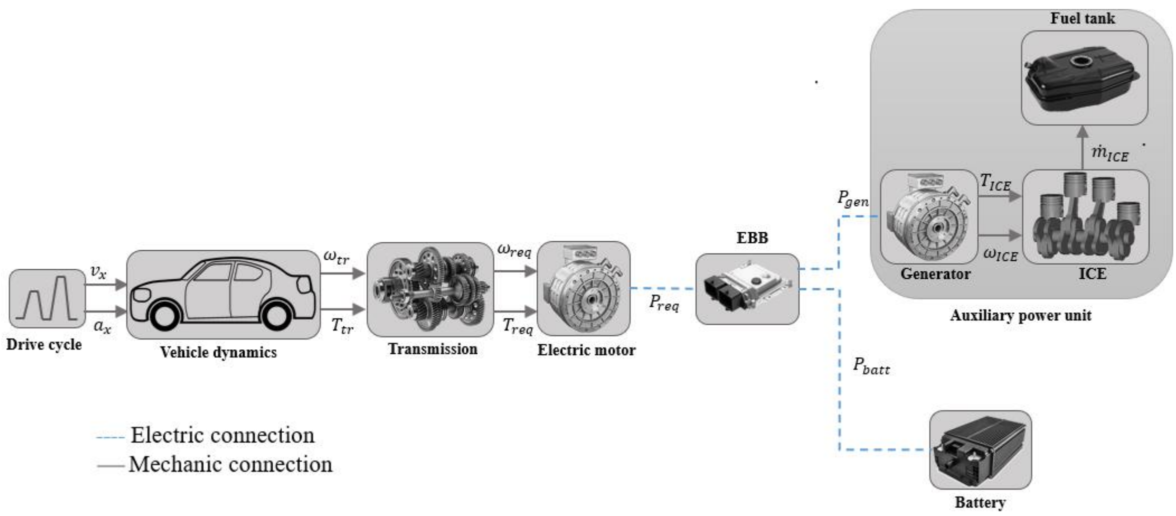

Figure 1. Powertrain structure of REEV

A backward simulation model of REEV is built in MATLAB/Simulink software for evaluating performances of ECMS. The model includes 25 kW engine together with 23.5 kW generator, a 125kW electric motor for traction and an 18.47 kWh rechargeable battery [3].

MINIMUM FUEL CONSUMPTION OF APU

To minimize fuel consumption of the APU, the engine and generator are modeled using a static efficiency map in this study [7]. The efficiency of generator is described by generator torque (T_{gen}) and angular speed (ω_{gen}).

$$\eta_{gen} = f(\omega_{gen}, T_{gen}) \tag{5}$$

$$P_{APU} = P_{ICE} * \eta_{gen} \tag{6}$$

The fuel consumption rate $\dot{m}_{ice}$ in $[g/s]$ is expressed by multiplying auxiliary power P_{APU} to brake specific fuel consumption $BSFC$ in $[g/kWh]$:

$$\dot{m}_{fuel} = BSFC * P_{APU} \tag{7}$$

For each APU power level, the minimal fuel consumption is obtained by extracting all unique power values from the power matrix using engine fuel and generator efficiency data. Subsequently, the minimal fuel consumption for those specific power values is calculated, and it is illustrated as Figure 2.

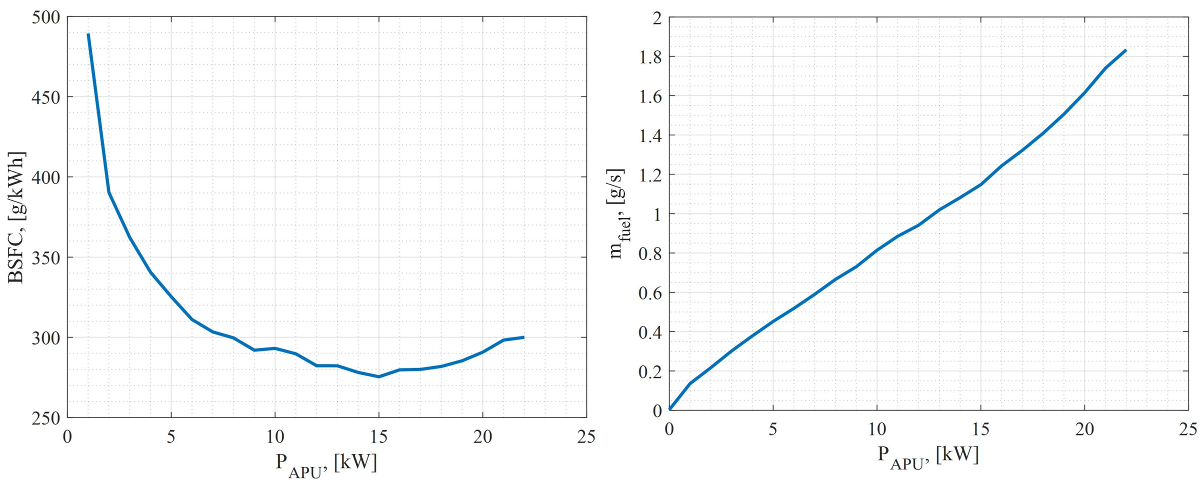

Figure 2. The specific optimal fuel consumption for each APU power

From the Figure 2, an empirical relationship for the fuel mass flow rate $\dot{m}_{fuel}$ can be derived. This equation will serve as a foundational element for implementing the ECMS in the next section.

EQUIVALENT CONSUMPTION MINIMIZATION STRATEGY

The main goal of ECMS is to minimize the overall energy consumption, considering both fuel and electrical energy usage by converting electrical energy costs to fuel consumption metric. At time t, the equivalent fuel consumption rate is represented as the sum of actual fuel consumption of APU $\dot{m}_{apu}(P_{apu}(t))$ and virtual consumption rate $\dot{m}_{batt}(P_{batt}(t))$ due to the battery charging or discharging [8].

$$\dot{m}_{eqv}(t) = \dot{m}_{apu}(P_{apu}(t)) + S_{SOC} * \dot{m}_{batt}(P_{batt}(t)) \quad (8)$$

$$\dot{m}_{apu}(t) = -0.00000836 * P_{apu}^4 + 0.0005042 * P_{apu}^3 + \quad (9)$$
$$+0.009673 * P_{apu}^2 + 0.1702 * P_{apu} + 0.0161$$

$$\dot{m}_{batt} = \begin{cases} s_{chg} * \frac{P_{batt}(t)}{LHV} & charging,\ P_{batt} > 0 \\ s_{dchg} * \frac{P_{batt}(t)}{LHV} & discharging,\ \ P_{batt} \leq 0 \end{cases} \quad (10)$$

Where S_{SOC} - penalty function, $[-]$; s_{chg} and s_{dchg} - charging and discharging equivalence factors, $[-]$;

In practical implementations, the equivalence factor is often implemented as a constant due to its simplicity and ease of calibration [9]. A penalty function is commonly employed to enforce SOC within admissible bounds. It acts as a correction term that penalizes deviations of the current $SOC(t)$ from the target SOC_{target}, as shown by the following expression [1]:

$$S_{soc}(\mathrm{t}) = s_0 + K_p * \left[SOC(t) - SOC_{target}\right] \quad (11)$$

Where s_0 - initial value of penalty function, $[-]$; K_p - proportional coefficient, $[-]$;

The optimization model for the ECMS is constructed by taking into account physical constraints. These constraints include the range of APU power, permissible limits for SOC and, charging and discharging limits of battery power.

The optimization model is presented below:

$$\begin{cases} min_{P_{APU},P_{batt}} \dot{J} = \dot{m}_{apu}(P_{apu}(t)) + \ S_{SOC} \ * \dot{m}_{batt}(P_{batt}(t)) \\ P_{EM} = P_{apu} + P_{batt} \\ SOC_{min} \leq SOC \leq SOC_{max} \\ P_{apu.min} \leq P_{apu} \leq P_{apu.max} \\ - P_{EM.max} \leq P_{batt} \leq P_{EM.max} \end{cases} \tag{12}$$

RESULTS AND DISCUSSION

In order to compare the results of fuel economy, the powertrain model is initially simulated using rule-based control strategy which is already conducted in previous works [10]. Subsequently, simulations are carried out with optimized ECMS controller. In both cases, the initial value of the battery SOC is set to 15.5%, and the simulations are conducted under UDDS and HWFET drive cycles.

Figure 6 shows the UDDS cycle results: required vehicle power with generator power, actual fuel consumption, and battery SOC. The results of fuel consumption [L/100 km] and SOC difference [%] are given for Rule -based and ECMS control strategies in Table 1. In the conducted simulations, the final battery SOC does not match the initial SOC value ($\Delta SOC = SOC_f - SOC_{init}$). Therefore, to enable a fair and accurate comparison of fuel consumption, the net change in SOC is converted into an equivalent fuel consumption. A linear correction form is selected to convert the net change in battery energy to an equivalent fuel consumption [11].

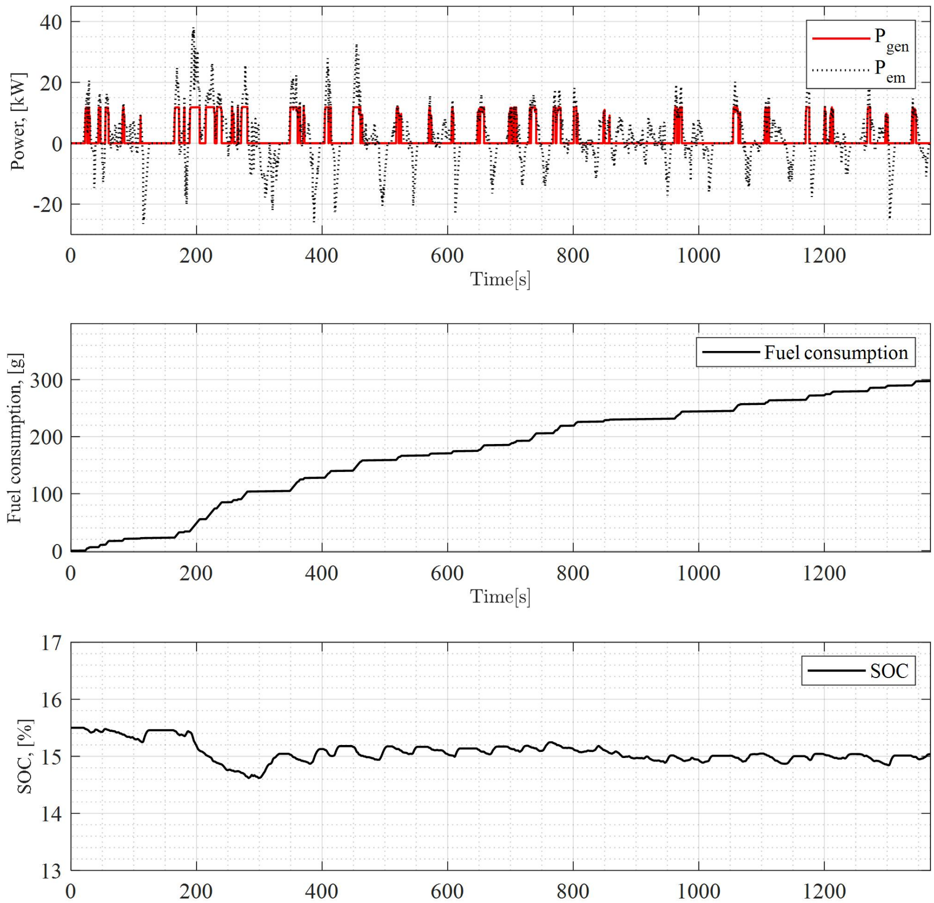

Figure 6. The simulation results for generator power, fuel consumption, and battery SOC under UDDS cycle

Table 1. Results of simulation for rule-based and ECMS strategies on UDDS and HWFET drive cycles

Drive cycle	Fuel economy, [L/100km]		ΔSOC [%]		Correction of fuel economy, [L/100 km]	
	Rule-based	ECMS	Rule-based	ECMS	Rule-based	ECMS
UDDS	4.45	4.19	-0.71	-0.46	4.7	4.47
HWFET	7.71	4.69	1.4	-3.11	6.91	6.59

CONCLUSION

This article presents a comparative analysis of the performance of rule-based and ECMS control strategies for Range Extended Electric Vehicles (REEVs). The ECMS controller is developed to operate the auxiliary power unit along its minimum fuel consumption line, thereby improving overall energy efficiency. The results demonstrate that the application of the ECMS control strategy leads to fuel consumption reductions of 4.89 % and 4.63 % compared to Rule-based strategy under UDDS and HWFET driving cycles, respectively.

ACKNOWLEDGEMENT

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Plug-in hybrid electric vehicles: Market and technology overview

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ABSTRACT

This report studies the dynamics of the global plug-in hybrid electric vehicle (PHEV) market, with a particular emphasis on its development in Uzbekistan. The study explores the key technical parameters of PHEVs, including internal combustion

engine (ICEs), electric motor types, battery capacities, and associated driving ranges. Comparative analysis and market research were conducted using available open sources.

The purpose of the study is to share and inform researchers and employees of related organizations about current trends and future directions in the PHEV sector.

Key words: New energy vehicles (NEVs), battery electric vehicles (BEVs), plug-in hybrid electric vehicles, internal combustion engines, Uzbekistan NEVs market.

1. New energy vehicles (NEVs) market volume with focus to PHEVs

In recent years, the NEVs market has shown rapid growth and the popularization of these cars is becoming more widespread among consumers. To achieve such results, comprehensive support was provided by the world's states, in particular, the introduction of subsidies for the production and sale of these cars, the development and support of new developments in NEVs sector and the development of this industry [1] . Consequently, global sales of NEVs reached about 17.1 million units in 2024, making up 20% of the total volume of global sales of passenger cars, including traditional cars with ICE. To underscore this dramatic growth, the 2024 sales data may be compared with 2014, revealing a 53-fold increase from only 320,000 units sold [2].

Looking ahead, projections suggest that NEV sales could reach 25 million units by the end of 2025. Impressively that China continues to grow in the global NEV market and sharing more than 64.7% of total worldwide NEV sales by the end of 2024, which is equal to 11 million units of vehicles [1] [3].

However, NEVs also can be divided into two main directions, it is plug-in hybrid vehicles and battery electric vehicles. Currently the share of PHEVs in NEVs lower than BEVs and equal to 41 % with 7,1 Million car sales in 2024 but it is 3 % higher comparing to 5 years old numbers where BEV was 62% [4] [5] . Furthermore, compared to the previous year when PHEV sales were 4.2 million units in 2023, sales increased by approximately 70% in 2024 [6].

One of the primary reasons for the increased consumer interest in PHEVs is the growing preference for vehicles that provide a balance between electric propulsion and conventional powertrains.

PHEVs has great advantages when traveling long distances compared to BEVs, including in cities or villages where charging infrastructure is not well developed and caution is required for drivers. In addition, due to the thoughtful combination of an internal combustion engine and an electric motor, cars consume little fuel and emit fewer greenhouse gases compared to traditional cars with internal combustion engines [7]. It well effects from economic point of view if low consumption is considered and meets ecological requirements for clean transportation.

Considering the factors discussed above, the sales of PHEVs have increased alongside the overall growth in BEV numbers during the given period, specifically last decades [8].

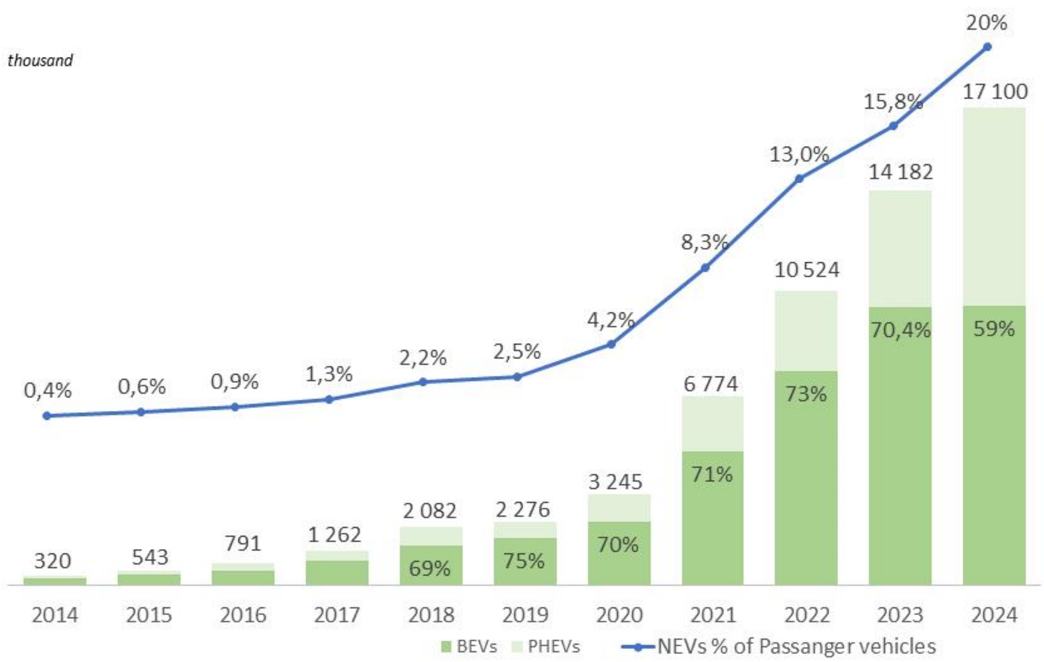

Figure 1. Global BEV and PHEV sales, including shares on PV sales

2. Brief introduction to PHEVs

PHEV combines an electric motor/s and a gasoline engine. Its battery can be recharged by plugging it in, allowing the car to run on electric motor and after period of time use the internal combustion engine [9] [10].

PHEVs can be categorized into three types based on their configuration: parallel hybrid, series hybrid, and series-parallel hybrid. All types/topologies will be discussed in more detail below:

1) In a parallel PHEV topology, the engine and electric motor are connected to the wheels via mechanical coupling. Both the electric motor and the engine can directly drive the wheels..

However, according to studies, these vehicles cannot travel long distances solely on electricity; they switch to engine power after approximately 75% of the battery energy is used. Moreover, during rapid acceleration, the vehicle automatically engages the ICE, even if the driving mode was set to EV mode [9] [10].

Furthermore, the key advantages of parallel hybrid topology are the ability to optimize fuel consumption when driving on the highway, allowing the ICE to operate at max efficient speed [11].

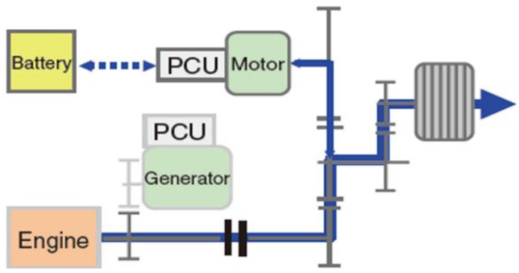

Figure 2. Parallel hybrid vehicle scheme

2) In a series hybrid topology, the car is driven by wheels with an electric motor and the internal combustion engine acts as a generator (unit is called an auxilary power unit) and charges the battery or motor with electricity. Figure 3 shows that the electric motor and the wheel are not connected to each other, but on the contrary, it directly transfers the generated energy to charge the battery. Nowadays, this type of car is becoming more and more popular and is called extended range electric vehicle

(EREV). This type of car is more suitable for urban driving conditions, and also reduce emission [9] [10].

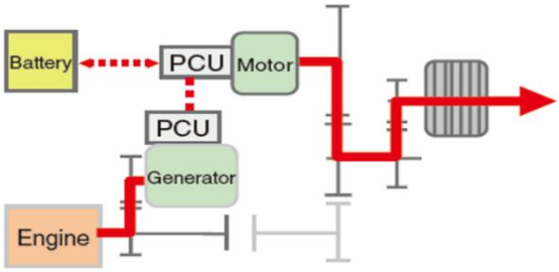

Figure 3. Series hybrid vehicle scheme

3) The serial-parallel topology combines both serial and parallel configurations. It allows the vehicle to move using an ICE, an electric motor, or both, depending on the driving conditions. At the same time, the residual power of the ICE simultaneously may charge the batteries. [9] [10].

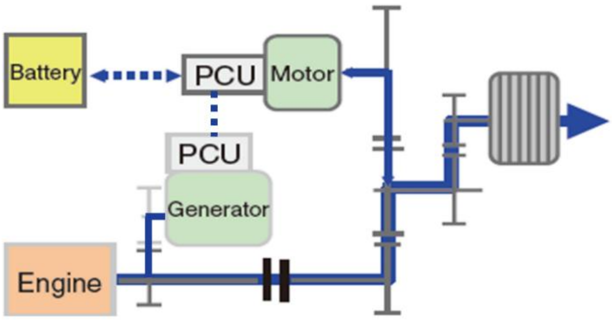

Figure 4. Series-parallel hybrid vehicle scheme

3. Battery packs on PHEVs

The key elements of any NEVs are considered to be batteries, and both PHEVs and BEVs are powered by a high-voltage battery system along with a conventional low-voltage battery pack that is installed in traditional vehicles.

While conventional vehicles with ICE uses lead-acid batteries for low-voltage power, the high-voltage batteries used in NEVs are typically made up of lithium based cells. Comparing to lead-acid batteries, lithium-ion technology offers significantly higher energy density, allowing these batteries to store more energy and hold a charge longer [12].

Today, most vehicle manufacturers use lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) type batteries, and both are the most common types used in all NEVs.

Table 1. compares NMC and LFP which are widely used by most NEV manufacturers and shows their strengths and weaknesses [13]:

Table 1. Differences between NMC and LFP batteries.

	NMCs	LFPs
Energy Density	Higher	Lower
Temperature	Better charging performance at low temperatures	Can tolerate high temperatures for longer periods of time.
Materials	Cobalt, nickel, and manganese are examples of more expensive materials to use.	Iron is more readily available than other minerals worldwide and more lithium is required.
Cost	Cost more	Cost less
Duration	Don't last as long	Last longer
End of life	More likely to be recycled	LFPs contain lower-value materials than NMCs, meaning the value of the collected materials is lower.
Cycle life	2,500 – 9,000 cycles	1,000 – 2,500 cycles
Safety	High thermal stability, lower fire risk	Higher risk due to cobalt and higher voltage chemistry

As far as both batteries have a distinct chemical composition, with specific advantages and limitations, there is no single battery technology that can be universally considered as the best choice for all NEVs.

PHEV battery capacities are comparatively modest, typically ranging from **8 kWh to 35 kWh in driving milage 55km to 210km respectively**, except in EREVs, where larger capacities are employed to achieve extended electric-only driving range. In contrast, full EVs more commonly utilize much larger batteries, averaging around **60 kWh or bigger** [14].

Except technical specification of batteries, the financial part is crucial for NEVs however recent price reductions of battery packs to approximately **$115 per kWh in 2024** (the steepest annual fall since 2017) have positively affected to the size of battery capacities offered in PHEVs [15]. As a result, PHEVs has started to provide the larger battery packs commonly between **26 kWh and 35 kWh**—which enable longer electric-range driving compared to previous generations. Today, according to study a PHEV with **35,6 kWh** battery pack can provide up to **210 km of all-electric range** on a single charge, offering consumers improved mileage, reduced weight, and lower ownership costs [16].

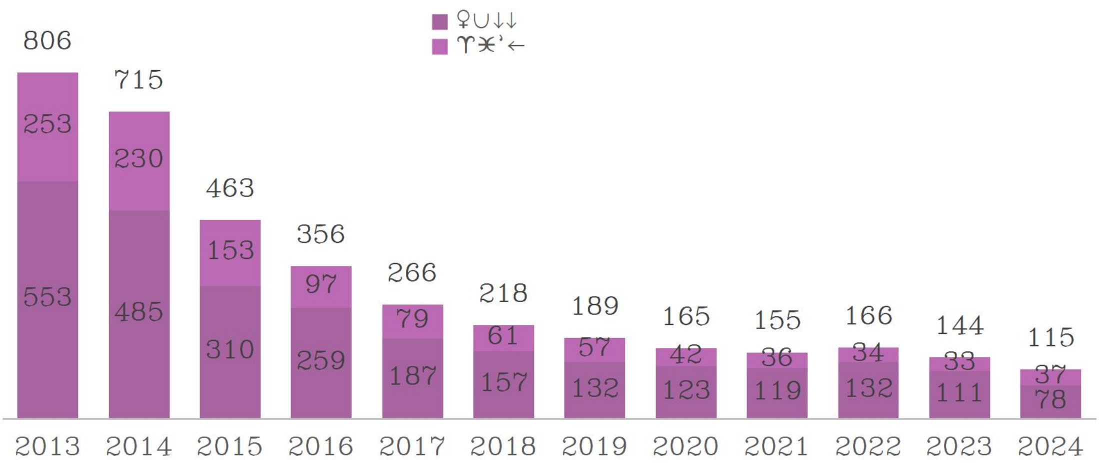

Figure 5. The average lithium-ion battery pack and cell price split in USD, 2013-2024 [17]

In addition, to extend the life of an NEVs battery, drivers should avoid frequent use of Fast - Charging stations and maintain a 20% to 80% charge. It is recommended to avoid letting the battery drop to a 0% charge and should limit charging up to 100%.

4. The power behind the wheels

PHEVs integrate all three principal propulsion subsystems - ICE, electric traction motors, and a hybrid energy management/control system.

4.1. PHEVs use more thermally efficient engines and intelligent hybrid systems that optimize power flow and greatly improve efficiency and emissions comparing to traditional ICE vehicles. Therefore, PHEVs often use Atkinson-cycle engines, which are more thermally efficient than the typical Otto-cycle engines used in traditional ICE vehicles [7]. ICEs of PHEVs typically achieve ~40% thermal efficiency, considerably higher than conventional Otto-cycle ICEs (~25–35%) [18]. As an example, in Table 2. There was given the main parameters of engine developed and produced by BYD mainly for PHEV models [19].

Table 2. The main parameters of engine of BYD PHEV models.

Model	BYD 472QA
Type	Atkinson-cycle engines
Displacement	1500 cc
Max power	81 KW
Max torque	135 Nm
Thermal efficiency	>42% (world's highest thermal efficiency)
Compression ratio	15.1:1

Addition to thermal efficiency, PHEVs recharged from cleaner grids emit approximately 20 – 40 % less GHG per kilometer compared to ICE vehicles [20].

4.2. While there are several types of electric motors, NEVs, including PHEVs, mainly use asynchronous induction motors, synchronous permanent magnet motors, and electrically excited synchronous motors. [21].

Asynchronous induction motor or induction motors, is a type of AC electric motor where the rotor's magnetic field is generated by electromagnetic induction from the stator's rotating magnetic field, rather than being directly powered [21] [22]. Typical efficiency of a asynchronous induction motor used in the automotive industry is around 90%. It's good characteristics make it a perfect on-demand motor in all wheel drive (AWD) NEVs [23].

Permanent magnet synchronous motors (PMSMs) use permanent magnets embedded in the rotor to generate a strong, consistent magnetic field. These motors are highly efficient, often reaching 94–95%, and offer superior power density. As a result, they are the most commonly used motor type in modern electric vehicles, especially front-wheel-drive (FWD) electric cars, which only require a single motor. However, costs are higher due to the use of permanent magnets (often containing rare earth elements).[21] [23] .

An electrically excited synchronous motor uses a separate winding to generate a magnetic field in the rotor. While they offer excellent torque and speed control, they are more complex and less efficient than PMSM. These motors are used in special applications, such as in some hybrid vehicles. , or in applications that require precise torque control [21] [23].

Table 3. Key differences between electric motor types

	Asynchronous induction motor	**Permanent Magnet Synchronous Motors**	**Electrically excited synchronous motor**
Cost	Low	High	Low
Efficiency	Low	Very high	High
Rare earth materials	No need	Need	No need
Cooling needs	Big	Low	Big
Power density	Low	High	High
Maintenance	Low	Low	High

An example of a vehicle that successfully uses a PMSM motor is the front-wheel drive BYD Song Plus DM-i, which uses a single front-mounted permanent magnet synchronous motor with a power of 145 kW and a torque of 325 N m. It provides smooth, all-electric driving and contributes to the vehicle's high hybrid performance [24].

5. Uzbekistan NEVs market and perspectives

The PHEV market has become a fascinating study in regional preferences and industrial strategy. To promote the adoption of NEVs in Uzbekistan, the government has issued a series of presidential decrees introducing tax exemptions for imported electric vehicles and subsidies aimed at establishing domestic NEV production [25] [26].

As a result, car imports in Uzbekistan surged by 57% in 2024, totaling approximately 41,500 NEVs, for the first time exceeding the share of ICE vehicles (44.2%). Among the imported NEVs, 58% equivalent to roughly 24,100 units were BEVs and rest of them are PHEVs [27] [28].

Notwithstanding the customs duty exemptions for NEVs in Uzbekistan, new PHEVs remain subject to a 15% customs duty on their import price. The discrepancy between the two policies has the effect of increasing the effective cost of PHEVs relative to BEVs. This, in turn, has the potential to influence consumer preferences and market dynamics [27] [29].

Table 4. General payments for the import of new NEVs to Uzbekistan

Items	**BEVs**	**PHEVs**
VAT	12%	12%
Scrap tax	120 BCV*	120 BCV*
Custom duties	0%	15%
The basic calculated value is equal to 32,7$		

However, the ongoing development of charging infrastructure and the country's vast distances, the demand for PHEVs in Uzbekistan is gradually increasing. One notable example of this trend is the establishment of a local BYD PHEV assembly facility in the Jizzakh region. At this plant, two PHEV models the BYD Song Plus DM-i Champion and the BYD Chazor are currently produced under a complete knock-down (CKD) process, which includes welding, painting, and full vehicle assembly [26] [30].

With the increasing presence of NEVs on the streets of Uzbek cities, public confidence in PHEVs and BEVs is steadily growing. This trend is illustrated in Figure 7 [31].

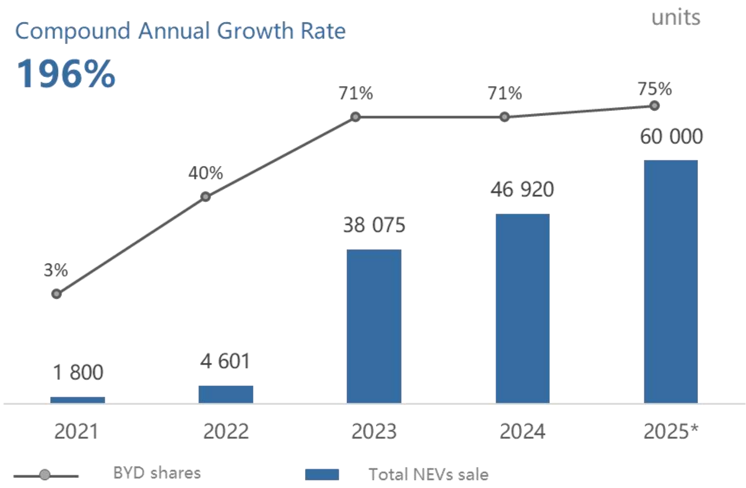

Figure 6. NEVs sales in Uzbekistan market and forecast

In 2024, overall sales of vehicles in Uzbekistan were 402,391 units, and out of these, market leader BYD accounted for 4.3% or nearly 17,132 units. Worth mentioning separately was the position that in the PHEV segment, the sales of BYD showcased a very strong predominance. BYD was the market leader in the PHEV segment with sales of 15,000 units, accounting for 90% of the market share. This overwhelming dominance is a sign of BYD's supremacy in the local PHEV market [31] [32]. In 2024, the best-selling PHEV model in Uzbekistan was BYD Song Plus, which was sold more than 8,100 units. The second-best models were the BYD Chazor, Song Pro, and Lixiang L9 [31]. Apart from BYD, there are several other players who are presently active in the PHEV segment of Uzbekistan. These brands listed above consist of such officially authorized names like Leapmotor, Chery, and Toyota, as well as grey market imports such as Lixiang and GAC. All of them contribute to enhancing the scope of PHEVs available to buyers of the domestic market [31].

In summary, although PHEVs possess more complicated drivetrain technology than BEVs, consumer confidence in PHEVs is slowly increasing in Uzbekistan.

It makes sense to anticipate that the PHEV market will see enormous growth in the near future. This can be due to a number of factors including the decline in battery prices, increase in ICE efficiency in PHEVs, and the overall reduction in the cost of vehicles. With the expanding market opportunities, BYD is considering introducing more PHEV models, other than Song Plus and Chazor, to Uzbekistan. The move is strategic in that it will diversify the products and expand consumer reach. Furthermore, the good investment climate and increasing demand for PHEVs offer a very good opportunity for other foreign manufacturers to establish local manufacturing facilities, thereby further enhancing the supply of such vehicles.

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A Framework for Quantitative Drivability Indexes in Electric Vehicles

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ABSTRACT

As electric vehicles (EV) emerge, there is an astounding transformation in the idea of vehicle driveability. Driveability testing has also been established over many years on ICE vehicles and cannot be tested on electric powertrains. In this paper, a new definition of quantitatively drivability indexes in EVs was suggested. First we revisit the clear definition of drivability and the huge labor done in traditional vehicles. We proceed to identify the existing gap in the critical evaluation of EVs and we propose a new performance measure and subjective factors connected to the psychophysics of EVs: longitudinal jerk, pedal feel and uniformity of regenerative braking. The paper explains the differences in the design of EV and ICE powertrains that necessitate this new approach. Lastly, we comment on future research directions. We also find that the development of standardized and objective EV drivability indexes is essential in advancing powertrain calibration and the overall consumer experience during the electric mobility age.

Keywords: Drivability, Electric Vehicles, Powertrain Control, Tip-In/Tip-Out.

1. INTRODUCTION

1.1. What is Drivability?

Drivability is a general description of the performance of the driveline, as perceived by the driver, and is a state of reaction to an operator action, and the state of smoothness of the powertrain in transient operation. In traditional (ICE) cars, a relatively old body of research has focused on the topic of drivability, which mostly concerns the smoothness of gear shifts and throttle response, tip-in/tip-out (where acceleration or deceleration accelerates), hesitation and the lack of unwanted behavior like engine surge or hesitation [1, 2]. The existence of objective ratings criteria and standards of institutions like SAE and ISO have historically impacted the OEMs by offering the OEMs a model in which their multi-dimensional feature can be quantified and improved as they strive to optimize performance, comfort, and quality.

1.2. Drivability in Electric Vehicles: An Emerging Challenge

Critical drivability concerns in electric vehicles (EVs) are not the same as critical concerns in vehicles with internal combustion engines (ICEs) because of the unique characteristics of the electric vehicle powertrain. Recent studies indicate increased attention is being given to the following: Longitudinal Jerk (where the near-instantaneous capability of the electric motor to deliver torque can create excessive jerk ($j = da/dt$) that may cause passenger discomfort and low refinement perception) [3]; Pedal Feel and Linearity in which the mapping of the accelerator pedal into the motor torque is done directly which requires careful tuning to avoid a binary response that is non-linear and may be very aggressive or very non-responsive; Regenerative Braking Blending which is a driver EV specific issue of These issues are not new; however, a standard, numerical measure of them is still not available in the field. This can cause engineers to rely on ICE derived strategy (ICE derived strategies not sufficient to capture EV driving experience).

2. Related works. Drivability in Conventional and Electric Vehicles.

Drivability Vehicle research represents an old discipline in ICE vehicles, but the knowledge/challenges of EVs are new and rapidly developing. In this part we examine the prevailing works in both the fields.

2.1. Conventional Vehicle Drivability: A Foundation of ICE Research.

ICE driveability research is most concerned with control mechanisms to counteract natural limitations of the combustion engine and multi-speed transmissions. Driveline oscillations and jerk is one of the aspects that are critical to examine and which are caused by elastic nature of ICE driveline. This task has been extensively researched in the context of automotive control systems, most famously by Kiencke and Nielsen [4], who looked at the model based control of pulsar type system, gave advice to model the dynamics of the driveline and suggested controllers to damp the torsional vibrations- the largest contribution to the unpleasant jerk. Along this line, Fredriksson et al. (2002) suggested to use active damping strategies and state observers to manage these oscillations, and the problem is considered as a disturbance rejection problem [5]. The basic to ICE development of drive ability is one of the essential subjective-objective correlation standards and norm. The subjective driveability tests are mostly based on the Society of Automotive Engineers (SAE) standard J1441; it is also used as a universal language between calibration engineers [1]. In addition, ISO 2631-1 gives some fundamental considerations on human exposure to whole body vibration on which are built the procedures of measuring jerk and acceleration that are most representative of human sensations of comfort [1].

2.2. Electric Vehicle Drivability: An Emerging Paradigm

EV drivability research, is independent, not of mechanical limits, but of the form of the motor instantaneous torque response to obtain a desired feel. Eller et al. suggest a co-simulation (i.e., LMS-AMESim/Simulink) to drive electric vehicles. [6]. It designs an RST torque filter that suppresses oscillations on the drive line in tip-in/ tip-out to increase comfort. The model is checked against track tests and used to calculate sensitivity studies of hardware parameters, including stiffness. Kim et al. compared the rating of the acceleration profile by ICEV and EV development specialists. [7]. It is quite obvious that ICEV experts preferred more smooth and steady characters, whereas EV experts were more liberal in terms of character response. The findings reveal that professional background has a dominant influence in driveability preferences. Using a proven simulation model and objective calibration, Scamarcio et al. contrasts six anti-jerk controllers in electric vehicle with a given eNMPC strategy to assess which mechanisms prove to be more effective and robust in various driving situations [8].

3. Drivability Assessment

3.1. Assessing Drivability: From Subjective Feel to Objective Indexes

This general rating of the driving capabilities of a vehicle depends on two fundamental, dovetailing pillars: the subjective and the objective. Another traditional method is perceptual discrimination which is a simulation of the essential human feel. It is all about expert evaluation drivers (golden drivers) who are extremely trained and at times consumer clinics visit to observe what has been planned and checked procedure was followed such as tip-in/tip-out, launch, part throttle acceleration, braking/regen blending, and steady-state cruising on a predefined test track or a predefined route. The objective assessment is the quantitative data/information that is the description of subjective feelings. This vehicle instrumentation is performed using sensors to measure significant physical parameters of the vehicle during the same maneuvers. Longitudinal acceleration (Gx) and its derivative jerk (da/dt), which is one of the key smoothness measures, are the most important measured data along with drive torque, accelerator pedal position, brake pedal force, engine/motor speed, vehicle speed, and sound quality data represented by a microphone. A closed-loop vehicle-calibration process can be achieved by logging intelligent performance data to data loggers and correlating the obtained information with the subjective driver rating during an offline analysis.

3.2. Existing Standards and Their Limitations. Though we cannot say any standardized test profile created specifically to characterize EV drivability, several current test patterns can be used as references with which to benchmark the test profile. One of the requirements of correlation between human perception and the proposed objective indices is that the SAE J1441 standard offers a credible subjective rating scale. Moreover, ISO 2631-1 provides the necessary guidelines in the field of human exposure to WBV and jerk, thus, the postulates of this standard may be applied to calculate the indicators of the Jerk Performance Index (JPI) as well. However, these standards have a significant limitation since they have been modeled based on the properties of the powertrain of internal combustion engine vehicles. Consequently, these older methods were not directly designed to solve the transient torque control challenges that are unique to electric powertrains and are not used to measure specific performance characteristics such as Regenerative Braking Consistency (RBC) or Pedal Linearity Index (PLI) et cetera. The aforementioned shortcoming in the capabilities of current approaches to electric vehicle (EV) technology underscores the need of a novel, EV-based framework.

4. Fundamental Differences Between EV and ICE Drivability

There is no single cause to the drivesability problems of electric vehicles; there is only a fundamental cause, which is a fundamental architectural difference between the EV and the ICE vehicle. In this section, the dissimilarities in the construction and operation are disaggregated to explain why EV driveability requires an entirely new evaluation paradigm.

4.1. Powertrain Architecture and Constructional Differences

Aspect	**Internal Combustion Engine (ICE) Vehicle**	**Electric Vehicle (EV)**
Prime Mover	Internal Combustion Engine	Electric Motor (Typically PMSM or Induction)
Torque Generation	Inherently slow and sequential. To work it must have air intake, compression, combustion, and exhaust. The torque output is in pulses and it is directly related to the engine speed.	Instantaneous and precise. The electromagnetically torque is generated, only one direction is necessary, current application and rotor speed are not taken into consideration. Hence, full torque is available from 0 RPM.
Energy Source	Liquid fuel (e.g., gasoline, diesel) stored in a tank.	Electrical energy stored in a high-voltage battery pack.

Aspect	Internal Combustion Engine (ICE) Vehicle	Electric Vehicle (EV)
Transmission	Multi-speed gearbox (6-10 speeds) is vital in maintaining the engine in its tight best power band.	Single-speed reduction gear. The electric motor's wide speed range and flat torque curve eliminate the need for multiple gears.
Driveline Components	Complex system including torque converter/clutch, prop shaft, differential, and numerous joints.	Typically less complex, and sometimes with a built-in unit (e.g. "e-Axle" combining motor, reducer, and differential) for easier management.
Natural Damping	Some sources of the damping action may be unintended, such as the torque converter and engine mounts which help to filter driveline vibrations and torque pulsations.	Minimal inherent damping. The direct, rigid connection from the motor to the wheels transmits torque variations and vibrations with high fidelity.
Braking System	Primarily hydraulic friction brakes. Engine braking provides minor deceleration.	Blended system combining regenerative braking (motor acting as a generator) and friction brakes.

5. Conclusion and Future Directions for EV Drivability Assessment

5.1. Future Research Directions

The proposed scheme is only a starting point, but there is much research to be conducted before one will be able to evaluate EV drivability. Some of the key aspects that should be considered include establishing global guidelines on electric vehicle-related testing procedures to ensure that the obtained results can be repeated. It will also require a very large-scale subjective analysis to establish correlations between objective measures and human perception, perhaps through machine learning to predict comfort models. Furthermore, since EVs are software-defined, one could argue that EVs can be thought of as personalizable vehicles with the software control of pedal response and regen braking algorithms to suit individual preferences. Study on driver-oriented metrics also ought to be extended to include full-body motions comfort on all passengers, and motion sickness prevention. Because of that, in the case of self-driving cars, R&D needs to be focused on the shift to the indexes of a more comfortable state of motion that does not require human intervention, the so-called Drivability indexes.

5.2. Concluding Remarks. The software-defined driving nature of an electric vehicle requires new language to evaluate, as it has been determined that this constitutes the only characteristic of an electric vehicle, not merely because it emits zero emissions, but because of the paper that has been presented by this document. In addition, when the industry is going mature, the EV market champions will be the manufacturers that can control the range and the performance but also master the refinements and the comfort. To proceed the robustness, the objectivity, and the standardization of the approaches in the quantification of the EV drivability, we must allow the engineers to design electric vehicles, which in addition to being efficient and powerful, are profoundly comfortable, intuitive, and pleasurable to drive. The next stage of EV drivability will be the transition of the subjective driving feel to the objective science of controlled electromagnetism.

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Electrification of carrier dump trucks in the conditions of exploitation of Uzbekistan

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ABSTRACT

The electrification of carrier dump trucks in Uzbekistan's mining industry is a promising step toward reducing fuel consumption and emissions. Operating conditions—long haul distances, steep ramps, high summer heat, winter cold, and heavy dust—present challenges for battery-electric and fuel-cell systems. Among available technologies, trolley-assist systems offer the most immediate benefits, cutting diesel use significantly on uphill segments while maintaining productivity. Battery-electric trucks are feasible for short and medium hauls if supported by high-power charging infrastructure and advanced cooling systems, while hybrid and hydrogen solutions remain longer-term options. Large-scale adoption requires mine-site power upgrades and integration of renewable energy to manage high electrical demand. A phased approach—beginning with trolley-assist deployment and pilot battery-electric trials—can ensure operational reliability, economic viability, and environmental benefits for Uzbekistan's mining sector.

Keywords: open-pit mining, trolley-assist, battery-electric haul trucks, Uzbekistan, duty-cycle modeling, total cost of ownership, mining decarbonization.

INTRODUCTION

The mining industry in Uzbekistan is a vital sector of the country's economy, rich in natural resources and with a strong potential for growth. Uzbekistan ranks among the world's leading countries for reserves of minerals such as gold, copper, uranium, and natural gas. The industry plays a key role in supporting both the domestic economy and export revenues.[1]

Gold: Uzbekistan is one of the top ten gold-producing countries globally. The Muruntau mine, located in the Navoi region, is among the largest open-pit gold mines in the world. Gold production is managed by Navoi Mining and Metallurgical Combinat (NMMC).

Uranium: The country is a leading supplier of uranium, which is mainly exported for use in nuclear power plants. Mining operations are carried out by the state company Navoiuran.[2]

Copper and Other Metals: Significant reserves of copper are concentrated in deposits such as Almalyk, mined by the Almalyk Mining and Metallurgical Complex (AMMC), which also extracts zinc, lead, and other non-ferrous metals.

Coal and Natural Gas: The Angren and Shargun coalfields supply coal for energy production, while natural gas resources are used domestically and for export.[3]

The mining sector contributes significantly to Uzbekistan's GDP and employment. It supports industries like construction, energy, and manufacturing. Exports of gold, uranium, and copper generate crucial foreign exchange earnings, especially as the government diversifies its economy beyond agriculture and textiles.

METHODOLOGY

In large-scale open-pit mining, distance and scale are massive. Ore, coal, or rock must be transported continuously from the excavation face to crushers, conveyors, or stockpiles.

Carrier dump trucks are the primary link in this logistics chain, providing:

•High-capacity transport of material over short but repeated trips.

•Flexibility to adapt to changing mine layouts as pits expand or deepen.

•Reliable movement of raw materials in areas where fixed conveyor systems are impractical or uneconomical.[4,5,6]

The need for mineral resources continues to grow globally, leading to increased open-pit mining activity and higher demand for heavy-duty haul trucks like BelAZ 75131. Traditionally, these trucks run on diesel, which results in high consumption and harmful emissions. Globally, billions of liters of diesel are burned annually in the mining industry, with 70-80% of that consumed by loaded trucks traveling uphill at low speeds. This generates large amounts of carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons, sulfur oxides, soot, and particulate matter.

It has been established that mining equipment, and especially mining dump trucks, are a significant source of black carbon emissions.

Black carbon itself is a product of incomplete combustion of diesel fuel and is the main component of particulate matter (PM). Even the largest particles, with a size of up to 2.5 microns (PM2.5), are 30 times smaller than the thickness of an average human hair.[7]

These fine particles enter the human lungs and cannot be removed once deposited. Studies have shown that these small particles pose serious health risks, causing cardiovascular diseases and premature death.

In June 2012, the World Health Organization (WHO) classified diesel engine exhaust as carcinogenic.

According to WHO findings, exposure to PM2.5 reduces average human life expectancy by 8.6 months.[8]

Black carbon is the third most powerful factor contributing to global climate change, following carbon dioxide (CO_2) and methane (CH_4).

Its effect is especially strong in the Arctic region.

When black carbon settles on snow and ice, it reduces their reflectivity (albedo), leading to:

- Increased absorption of solar radiation,
- Rising air temperatures,
- Accelerated melting of snow and ice.

These effects make the Arctic particularly vulnerable to black carbon emissions, highlighting the urgent need for emission reduction measures, especially from heavy-duty diesel-powered mining vehicles such as dump trucks.[9] There is an information about estimating CO emissions for carrier dump trucks in Uzbekistan (table-1)

Table-1. Estimating CO Emissions for Carrier Dump Trucks in Uzbekistan

№	Operating mode / condition	Estimated CO emission rate (g/h or g/kWh)	Key assumptions / comment
1	Cold start / engine warm-up	High—possibly 20-100 g CO per hour (depending on size)	Poor combustion initially; emission control systems not yet up to temperature.
2	Idling (no load)	~ 5-30 g CO per hour	Diesel engines produce a lot of CO when idling poorly, especially older engines.
3	Loaded haul uphill	~ 1-5 g CO per kWh of engine output	Under load, combustion is more complete, CO emissions drop relative to fuel consumption.
4	Lower load, partial load	Higher per unit power (perhaps double to triple than at full load)	Because of incomplete combustion, etc.
5	Well-maintained, modern engine, good fuel, proper operating temperature	Lower bound: CO might be < 1 g/kWh in many working modes	Emissions control, injection timing, air-fuel ratio, turbocharging, etc. help reduce CO.

The electrification of mining dump trucks is a key step toward creating a more sustainable and cost-efficient mining industry. Traditional diesel-powered haul trucks are among the largest sources of greenhouse gas emissions, including black carbon (soot), CO_2, NO_x, and other harmful pollutants. Transitioning to electric or hybrid technologies significantly reduces both environmental impact and operating costs.[10]

The main reasons of electrification of carrier dump trucks:

- Reduction of emissions: Diesel dump trucks produce massive amounts of CO_2, NO_x, and black carbon, which negatively impact air quality, workers' health, and global climate.
- Noise reduction: Electric motors are quieter, improving working conditions in mining areas.
- Support for national sustainability goals: Countries like Uzbekistan are increasing their focus on environmental policies and clean energy integration.

Now days there are few types of electrification technologies. Below is a figure 1 showing some of the electrification methods.

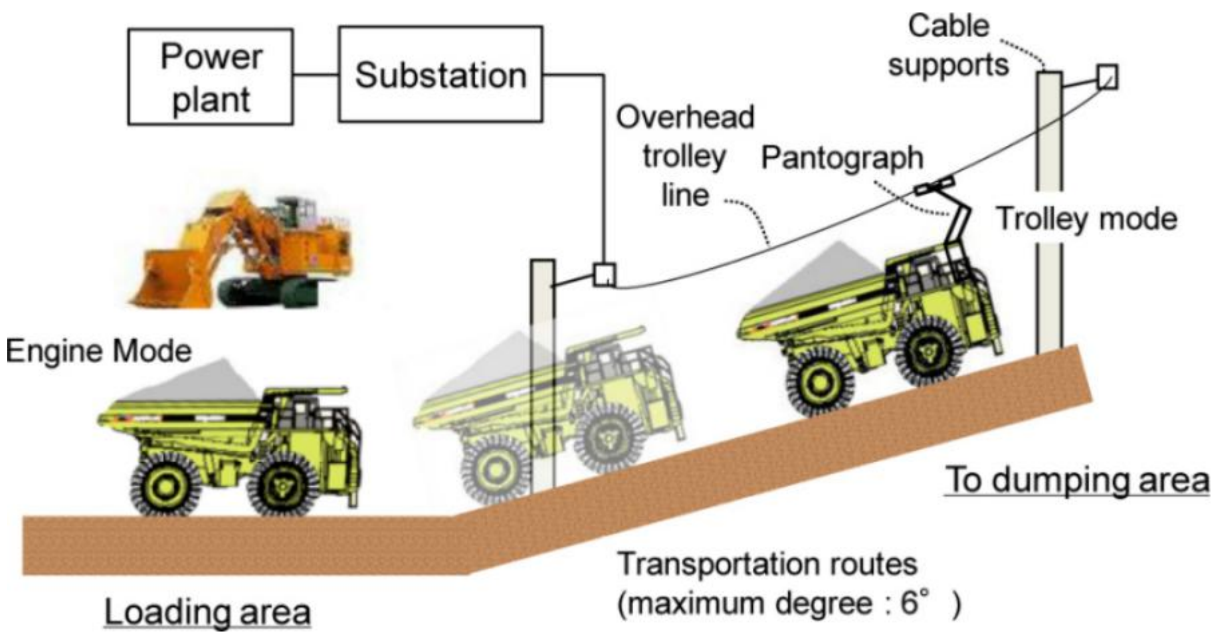

Figure 1 - Trolley-assisted haul truck scheme

The trolley assist system is a configuration that allows maintaining electrical supply to the propel motors of the extraction trucks from the electric grid of the mine, by engaging the truck on the trolley lines as shown in the illustration below. Among the benefits provided using the trolley system is the increase of speed on travel up trajectories, which produces an increase of material transported, and fuel savings and reduction in the carbon footprint of the transport operations.

CONCLUSIONS

Trolley is an essential step in the decarbonization process which can be implemented today to make significant reductions in GHG emissions and certainly will be a part of zero emission mining going forward. Trolley Assist will require a robust implementation plan but the rewards are huge. This has been a technology that has been available for many years on many truck sizes. Yet mining companies have been reluctant to adopt this in spite of (some of them) having excellent conditions – meaning long uphill hauls on ramps that are quite static. Especially in deep copper pits the fuel consumption reduction and speed increase are impressive. Main reason given is usually the reduced flexibility. Trolley has lots of advantages, but you need to consider the total cycle.

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The Importance of the Green Wave Traffic Management Method on Urban Highways

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ABSTRACT

This article provides a scientific and analytical discussion on the significance of the Green Wave technology in improving traffic management on urban arterial roads. The study explores the possibilities of ensuring uninterrupted vehicle movement through the synchronization of traffic light systems. Additionally, the role of Green Wave technology in reducing congestion, saving time, optimizing fuel consumption, and minimizing environmental damage is assessed using statistical analysis methods. The importance of implementing Green Wave technology under local and regional traffic conditions is examined through a comparative analysis of international experiences. The findings of this research contribute to enhancing the efficiency of traffic management systems by introducing innovative approaches to urban transport infrastructure.

Keywords: Green Wave, traffic management, traffic light synchronization, congestion reduction, environmental efficiency.

INTRODUCTION

Today, the development of urban transport infrastructure is giving rise to complex challenges related to the growing mobility needs of the population. The increasing population density and the rising number of vehicles are causing traffic congestion, which leads not only to economic losses but also to the exacerbation of environmental problems. In particular, the issue of effectively managing traffic flow on urban highways has become critically important.

Modern technologies play a significant role in improving traffic management systems. One such technology is the "Green Wave" system, which synchronizes traffic lights (Figure 1) to ensure the continuous movement of vehicles. This technology not only saves time for commuters but also reduces fuel consumption by vehicles and minimizes environmental harm.

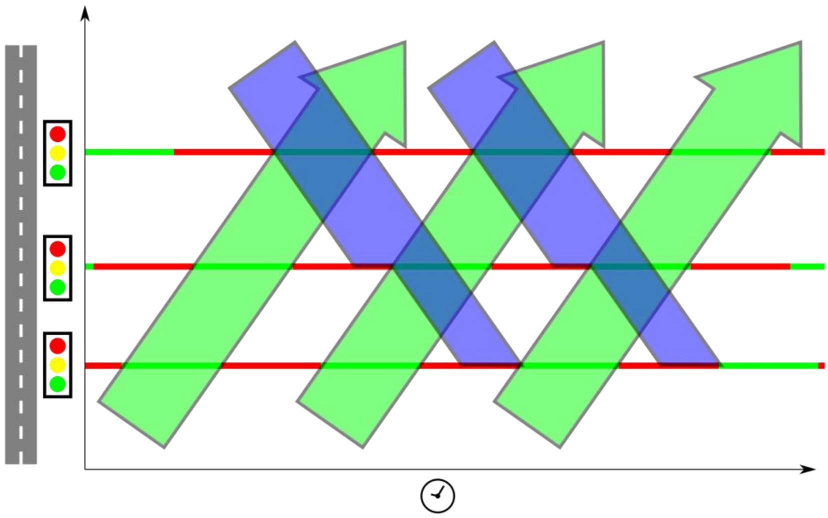

Figure 1. Diagram of traffic light synchronization

This diagram illustrates the concept of the "Green Wave," which involves the synchronization of traffic lights. This concept is used to efficiently manage traffic flows and enable vehicles to move without interruptions.

Caption for Figure 1:

1. Vertical Axes: Represent individual traffic lights (e.g., A, B, C). Each line corresponds to one traffic light.

2. Horizontal Lines: Reflect the time axis. Each line indicates the passage of time.

3. Green Lines: Represent green waves, i.e., intervals during which vehicles traveling at a designated speed can pass through traffic lights without encountering a red light.

4. Blue and Green Arrows: Indicate vehicle movement. These arrows represent the uninterrupted flow of traffic resulting from synchronized traffic lights.

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5. Red Lines: Indicate the red phase of the traffic light. If vehicles arrive during this time, they are forced to stop.

If a vehicle travels at the designated speed, it stays within the green wave and encounters green lights, remaining “in the wave.” This synchronization improves traffic flow and reduces fuel consumption. The distance between traffic lights and the timing of green light activation must be precisely synchronized.

Main Section. International experiences demonstrate that the implementation of green wave technology has led to significant positive changes in urban transport systems. For example, in Munich, Germany, this technology reduced traffic congestion by 20% and fuel consumption by 15% [1]. In Los Angeles, USA, the green wave system has enabled drivers to save an average of 30 minutes daily [2]. In Shanghai, China, this technology has contributed to a 25% reduction in harmful gas emissions released into the atmosphere [3].

Globally, the coverage of green wave traffic light synchronization is highest in Germany, reaching 85% (Figure 2). Following Germany are the USA, Japan, China, Brazil, and India. Unlike Germany and Japan, although the USA, China, Brazil, and India are countries with large territorial areas, their traffic light synchronization coverage is relatively high at 75%, 65%, 55%, and 45%, respectively.

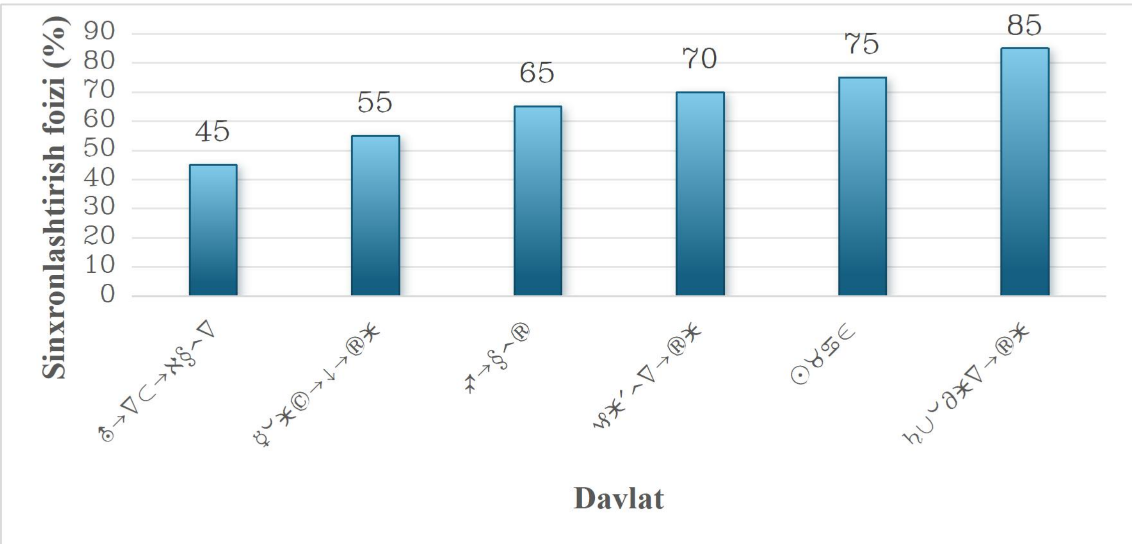

Figure 2. Coverage of green wave traffic light synchronization

In developing countries, rapid urbanization and the expansion of transportation networks frequently lead to traffic congestion issues. Green wave traffic lights synchronize traffic flow, significantly reducing unnecessary vehicle stops, fuel consumption, and carbon emissions.

From 2010 to 2025, the coverage of traffic light synchronization has shown growth in all the aforementioned countries over five-year intervals. The growth rate in Germany, the USA, and China has been assessed at nearly similar levels; however, between 2015 and 2025, China experienced a slightly higher growth rate, approximately 4% more than Germany and the USA. Japan and Brazil recorded a consistent 30% growth in synchronization coverage from 2010 to 2025, but by the end of this period, Japan surpassed China by 2% due to a higher growth rate. Although India recorded the lowest coverage, its growth rate (20%) from 2015 onward matched that of Japan and Brazil by 2025 (Figure 3).

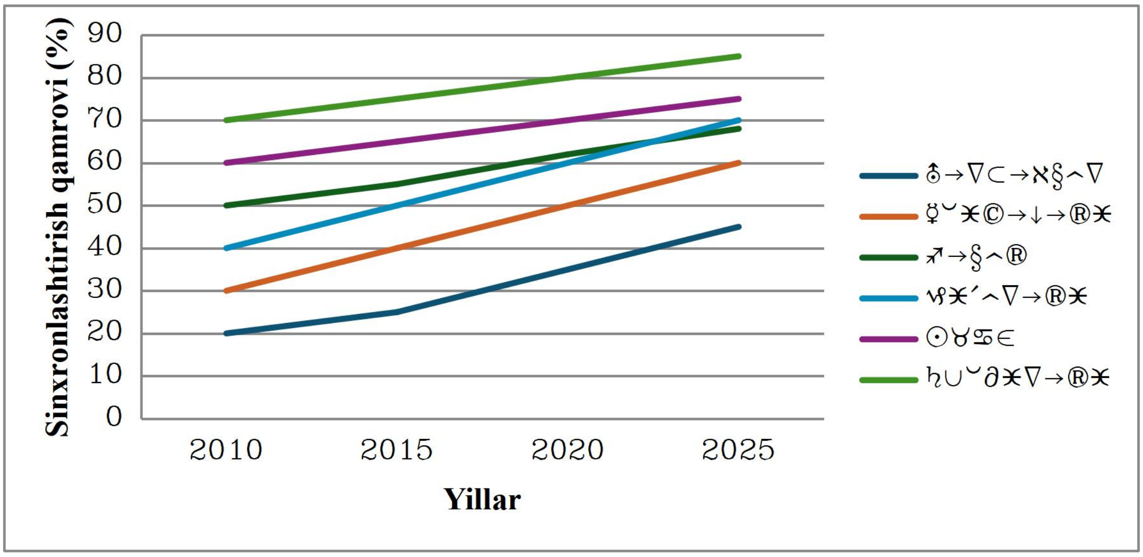

Figure 3. Traffic light synchronization coverage over time intervals.

Scientific Prospects of Green Wave Technology in Uzbekistan. The scientifically grounded prospects of green wave technology in Uzbekistan are based on the goals of modernizing the country's transport infrastructure and ensuring environmental sustainability. The expansion of urban infrastructure and the increasing density of vehicle traffic have created a need to optimize traffic management systems. Green wave technology offers an advanced solution in this regard, enabling the reduction of traffic congestion, acceleration of passenger and freight transport processes, and reduction of fuel consumption and carbon emissions through traffic light synchronization.

One of the scientifically supported prospects is adapting this technology to local conditions, taking into account the specific characteristics of traffic flows, pedestrian needs, and public transportation systems in Uzbekistan's cities. For instance, in large cities like Tashkent, analyzing vehicle traffic and implementing the green wave system on major transport arteries could reduce travel time by 20–30% and enhance fuel efficiency.

Additionally, scientific research is exploring the integration of artificial intelligence (AI) and Internet of Things (IoT) technologies into the green wave system. This would allow the system to monitor traffic flows in real time and implement adaptive management. Furthermore, studying local and international experiences, optimizing resources, and securing financial support for infrastructure projects are critical before implementing the technology.

The introduction of green wave technology in Uzbekistan's cities, along with delivering economic, environmental, and social benefits, demonstrates the country's capability to adopt advanced traffic management technologies.

CONCLUSION

Green wave technology holds significant importance for optimizing Uzbekistan's transport system, reducing traffic congestion, and ensuring environmental sustainability. Its implementation brings economic and environmental benefits by reducing fuel consumption, saving commuters' time, and decreasing carbon emissions. Scientifically tailored research adapted to local conditions, integration with AI and IoT technologies, and leveraging international experience will enable the effective implementation of this process.

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The Impact of Vehicles with Automatic Transmission on Traffic Flow Speed in Urban Streets

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ABSTRACT

The increasing prevalence of vehicles with automatic transmission significantly impacts urban transport dynamics. This article examines the influence of automatic transmission vehicles on traffic flow speed in urban streets, focusing on their advantages and potential challenges. Through a combination of theoretical calculations, simulations, and empirical experiments, the impact of these vehicles on traffic flow speed and congestion levels is evaluated. The research aims to provide insights for urban planning and transportation management strategies.

Keywords: Automatic transmission, urban traffic flow, congestion, transportation management, smart cities.

INTRODUCTION

In recent years, the automotive industry has witnessed a significant shift toward vehicles with automatic transmission. This shift is associated with improved driving convenience, reduced driver fatigue, and the increasing complexity of urban transport conditions. As cities continue to expand and urbanization accelerates, traffic congestion on roads has become a critical issue affecting quality of life and economic efficiency. Understanding the impact of automatic transmission vehicles on traffic flow speed is essential for developing effective mobility management strategies.

The objective of this study is to investigate the impact of automatic transmission vehicles on traffic flow speed in urban streets. Automatic transmission vehicles contribute to smoother traffic flow and reduced congestion by maintaining stable speeds and requiring fewer gear changes. However, their interaction with manual transmission vehicles in mixed traffic conditions may pose challenges that need to be addressed.

PROBLEM STATEMENT

The growing number of automatic transmission vehicles presents both opportunities and challenges for urban transportation management. While these vehicles can enhance driving convenience and reduce driver fatigue, their impact on traffic flow speed, particularly in densely populated urban areas, remains understudied. Key questions include their effects on movement speed, congestion levels, and overall traffic efficiency.

RELEVANCE OF THE TOPIC

The relevance of studying the impact of automatic transmission vehicles on urban traffic flow speed lies in the potential benefits for urban planning and transportation management. The Decree of the President of the Republic of Uzbekistan No. 190, dated April 4, 2022, on "Measures to Ensure Reliable Human Safety on Roads and Significantly Reduce Fatalities" is aimed at addressing this issue. With the rise of smart cities and the need for efficient transportation systems, understanding the dynamics of traffic flow with different types of vehicles is crucial. This study aims to provide insights to inform road traffic management strategies.

LITERATURE REVIEW

Several studies have explored the impact of different vehicle types on traffic flow speed. For instance, Smith et al. (2020) found that automatic transmission vehicles maintain more stable speeds compared to manual transmission vehicles, contributing to smoother traffic flow. Similarly, Jones and Brown (2019) emphasized that automatic transmission vehicles reduce the frequency of stop-and-go traffic, a key contributor to urban congestion. However, there is a need for comprehensive studies focusing specifically on the impact of these vehicles in mixed traffic conditions typical of urban streets.

METHODOLOGY

To address the issue, this study proposes a comprehensive analysis combining theoretical calculations and empirical experiments. By simulating traffic scenarios and conducting real-world experiments, we assess the impact of automatic transmission vehicles on traffic flow speed and identify potential directions for improving transportation management.

THEORETICAL FRAMEWORK

The theoretical foundation of this study involves modeling traffic flow using various parameters, including vehicle speed, acceleration, and deceleration values. By integrating data on the performance of automatic transmission vehicles, we can simulate traffic scenarios and estimate their impact on overall traffic efficiency. The primary equations used in the calculations include the fundamental traffic flow equation:

$$Q = k \cdot v$$

Here, Q is the traffic flow rate, k is the traffic flow density, and v is the average vehicle speed.

SIMULATION

Traffic simulation software is used to create various scenarios with different proportions of vehicles. The simulation parameters include vehicle speed limits, traffic signal timings, and road network configurations. By varying the share of automatic transmission vehicles, their impact on traffic flow and congestion levels is observed.

EMPIRICAL EXPERIMENTS

The experimental component of this study involves collecting data from urban streets with a significant presence of automatic transmission vehicles. Traffic flow speed and congestion levels are measured using traffic sensors and cameras. The data is analyzed to identify the relationship between the proportion of automatic transmission vehicles and traffic flow efficiency.

RESULTS

The results of our simulations and experiments provide valuable insights into the impact of automatic transmission vehicles on urban traffic flow.

SIMULATION RESULTS

The simulation results indicate that increasing the share of automatic transmission vehicles in congested conditions leads to smoother traffic flow and reduced congestion. In scenarios with a higher proportion of automatic transmission vehicles, the average vehicle speed increased by 10%, while the number of stop-and-go situations decreased by 15%.

Table 1. Simulation Results of Traffic Flow

Share of Automatic Transmission Vehicles (%)	Average Traffic Flow Speed (km/h)	Stop-and-Go Situations (per km)	Traffic Light Crossing Time (seconds)	Traffic Light Waiting Time (seconds)
0	30	18	28	6
25	32	16	26	5.5
50	35	14	24	5
75	37	13	23	4.5
100	40	12	22	4

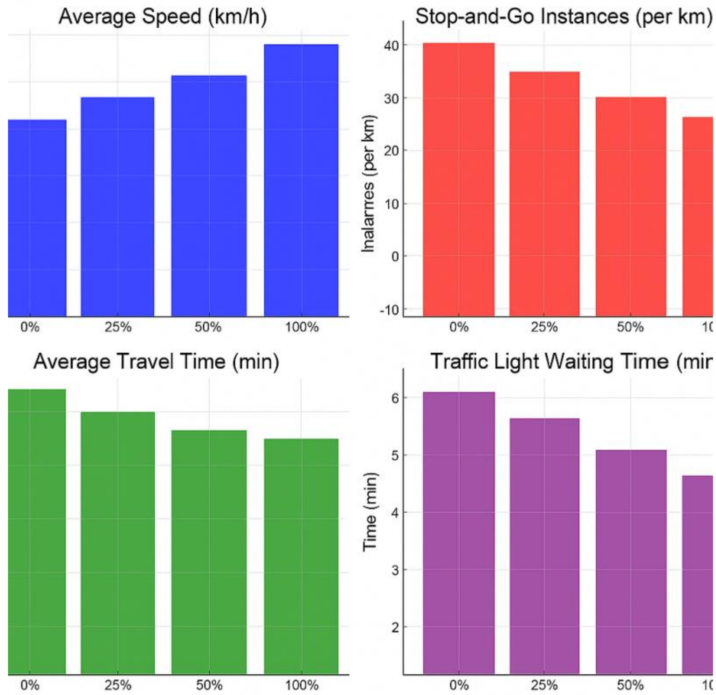

Figure 1. The Impact of Automatic Transmission Vehicles on Traffic Indicators.

EMPIRICAL RESULTS

Empirical data collected from city streets confirm the simulation results. Streets with a higher share of vehicles equipped with automatic transmissions experienced less congestion and more stable traffic flow. The data showed a 12% reduction in average travel time and a 20% decrease in waiting time at traffic lights.

Table 2. Empirical Results.

Measurement Parameters	Manual Transmission	Automatic Transmission	Improvement
Average Traffic Flow Speed (km/h)	35	38	+10%
Stop-and-Go Instances (per km)	15	12	-20%
Traffic Flow Signal Crossing Time (seconds)	25	22	-12%
Traffic Light Waiting Time	5	4	-20%

(seconds)			

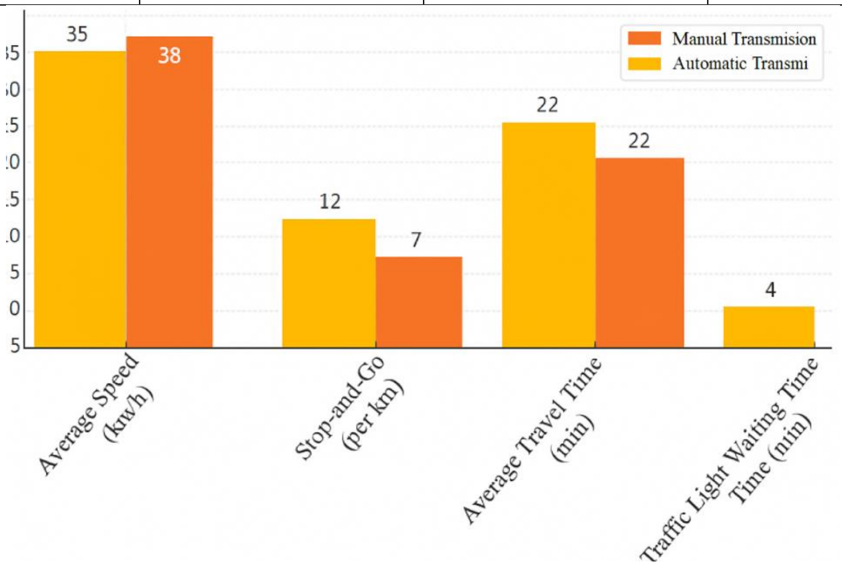

Figure 2. Comparison of Performance Indicators Between Manual and Automatic Transmission Vehicles.

ANALYSIS OF RESULTS

The experimental results were analyzed to identify trends and parameters. Vehicles with automatic transmissions positively influence traffic flow by maintaining a more consistent speed and reducing stop-and-go behavior. At the same time, potential challenges—such as their behavior in mixed traffic conditions—are also considered.

In mixed traffic environments, the interaction between automatic and manual transmission vehicles can present certain difficulties. Manual vehicles, which often require more frequent gear changes and may exhibit greater speed variability, can disrupt the smoother flow of automatic transmission vehicles. This highlights the need for traffic management strategies that consider the presence of both vehicle types.

Discussion. The findings of this study are highly relevant for urban traffic management and planning. The positive impact of automatic transmission vehicles on traffic flow suggests that encouraging their use—through incentives and social reforms—could be beneficial. Additionally, traffic management strategies should be adapted to account for the coexistence of both automatic and manual transmission vehicles in order to optimize overall traffic flow.

One potential approach is the implementation of designated lanes, similar to those for high-occupancy vehicles (HOV), specifically for certain types of vehicles. This can help separate traffic flows and minimize interaction between different transmission types, contributing to smoother traffic movement. Moreover, traffic light signal timings could be optimized to better accommodate the stable speed profiles of vehicles with automatic transmissions.

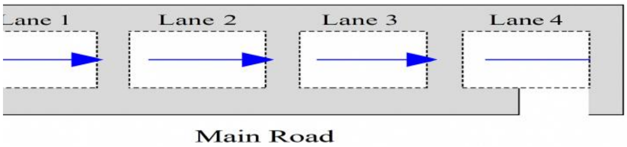

Figure 3. Lane Segregation for Smoothing Traffic Flow.

CONCLUSION

This study aimed to provide a comprehensive understanding of the impact of automatic transmission vehicles on urban traffic flow. The research contributes to the development of more effective traffic management strategies and urban planning policies, ultimately leading to improved transportation conditions and reduced congestion in cities.

The study highlights the potential advantages of automatic transmission vehicles in urban traffic settings, including smoother traffic flow and reduced congestion. However, the interaction between different types of vehicles introduces challenges that need to be addressed through appropriate traffic management strategies. Future research should focus on developing and testing these strategies under real-world conditions to validate the findings of this study.

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INNOVATIONS IN SUSTAINABLE TRANSPORTATION EDUCATION AND RESEARCH

Modern Technologies in Driver Training and Their Future

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ABSTRACT

This article focuses on the analysis of innovative technologies and various research practices implemented based on international experiences to develop safe driving behaviors among drivers as responsible road users. The extent to which innovative technologies are utilized in addressing the issue of reducing road traffic incidents is presented, along with data from psychological studies aimed at assessing their effectiveness. Special attention is given to the use of virtual reality applications, which offer opportunities for educating primary road users and developing their safe behavior skills. Studies illustrating the implementation and application of immersive driver training—defined as a perceptual method involving exposure to artificially created environments capable of generating a sense of presence—are provided as examples. The reviewed innovative technologies contribute to the development of new practical approaches in driver training and in enhancing driving competencies.

Keywords: Driver, training of road users, road traffic incident, innovative educational technologies, traffic regulations, driver psychology.

INTRODUCTION

It is well known that in recent years, comprehensive organizational and practical measures have been implemented in our country to ensure reliable protection of human safety on roads and to reduce the number of fatalities, as part of efforts to improve the road safety system.

Today, road traffic incidents have become one of the major global problems worldwide. According to data from the World Health Organization, 1.35 million people die annually in road traffic incidents (RTIs) globally. Road traffic incidents rank as the eighth leading cause of death worldwide, and they are the number one cause of death among people aged 15 to 29 years [1,5].

At the same time, despite the measures being implemented, the number of fatal road traffic incidents remains high, indicating the urgent need for fundamental reforms in the road safety management system [1,2,3,4].

In particular, there is a pressing need to fully align road infrastructure with modern road safety requirements, establish an effective system aimed at timely prevention of traffic violations, and widely implement digital technologies capable of minimizing the human factor in traffic safety [1,2,3,4].

According to the Strategy for the Development of the Public Safety System in the Republic of Uzbekistan for 2022–2025, and under the conditions of the New Uzbekistan, ensuring the reliable protection of human life and health on roads under any circumstances has been defined by our President and Government as a top priority. The following key tasks have been set:

- modernizing and improving the quality of road infrastructure, and creating safe and reliable conditions for road users based on the hierarchy of mobility priorities: "pedestrians – public transport – cycling – motorized transport";
- enhancing the quality of driver training by introducing innovative pedagogical technologies into the system of initial training, retraining, and upgrading the qualifications of drivers, thus bringing the educational process to a qualitatively new level;
- raising the culture of compliance with traffic regulations among drivers and pedestrians, and ensuring consistent enforcement of penalties for any violations;
- introducing early road safety education from childhood, and implementing this practice in pre-school educational institutions and general education schools;
- achieving full digitalization of traffic management, and implementing new control and management systems through the adoption of advanced information and communication technologies.

Particularly, in pursuit of fundamentally modernizing and improving the quality of the driver training system, significant changes have taken place in this area. Without exception, regardless of their organizational and legal form, the licensing procedure for all educational institutions engaged in training, retraining, and upgrading the qualifications of drivers (hereinafter referred to as "driving schools") and for examination centers has been revised, undoubtedly marking a major transformation in the entire system.

Today, we can observe that recent reforms in the teaching methodology at driving schools are yielding positive results. One of the main challenges in promoting innovative technologies for developing safe road user behavior among drivers is not necessarily their development process (although this certainly plays an important role), but rather the assessment of their effectiveness in practical implementation for reducing traffic accidents. Over the past decades, an increasing number of studies in traffic psychology have emerged, focusing on evaluating the effectiveness of these technologies and their impact on developing safe behavioral skills in the automotive environment [18].

In accordance with the implementation of the Decree No. PQ-4913 of the President of the Republic of Uzbekistan dated December 7, 2020, "On Additional Measures for Involving the Private Sector in Areas Regulated by the State," private examination centers established by entrepreneurial entities authorized to conduct theoretical and practical driver’s license exams have begun their operations.

Figure 1. Modern training classrooms for driver education.

These centers are expected to conduct exams fully free from human intervention, using an automated electronic system. This will help eliminate corruption-related issues that have previously arisen during the process of taking theoretical and practical driver's license examinations.

It is worth emphasizing that around the world, innovative educational technologies based on virtual reality (VR) and augmented reality (AR) are increasingly being recognized as advanced teaching methods. These technologies are widely applied in driver training and have demonstrated high effectiveness. This not only confirms their efficiency but also highlights the pedagogical suitability of using VR and AR applications in the learning process. The potential of VR-based innovative technologies is grounded in well-established principles of effective learning practices validated in psychology and adult education (andragogy).

At the same time, a paradoxical situation arises: on the one hand, there is growing and sustained interest in using VR and AR applications for driver training [13]; on the other hand, the lack of sufficient data on the effectiveness of these technologies significantly complicates their development and implementation.

It should be noted that the use of such training tools for shaping safe road user behavior among drivers is currently gaining increasing momentum across various approaches and practices. In driver education, as well as in correcting their road behavior, the use of virtual and augmented reality elements stands out as an area requiring special attention and further research.

Immersive learning is a modern educational method that involves specific techniques and tools, including VR applications, and has recently been applied not only to drivers but also to pedestrians, based on targeted behavioral corrections. Educational programs for school students, designed around virtual environments to teach safe road-crossing skills, serve as a good example of this approach. Experimental studies in this field have demonstrated high effectiveness of immersive training through the use of various virtual scenario models. The learning process itself can be described as a "spiral cycle of four sequential stages," involving the following transitions:

- repeating the sequence from direct experience to reflection on that experience, and then to enhanced direct experience;
- moving from reflective observation to the formation of abstract concepts;
- progressing from conceptualization to active experimentation and practical testing;
- applying the acquired knowledge in real-life practice [15,16].

It should be noted that training sessions can begin at any stage of this cyclical model. The proposed experimental learning scheme involves providing training participants with an enhanced experience in a specific traffic situation, followed by a structured discussion and a process of understanding and reflecting on the experience gained. Learning is thus organized as a process of knowledge acquisition, construction, and transformation by students. This process is assumed to occur through the interaction between two interrelated dimensions of knowledge: concrete experience (acquisition) and abstract conceptualization (transformation) [Systematic Review, 2020].

Currently, the authors of ELT (Experiential Learning Theory) [Systematic Review, 2020] are discussing eight core principles of adult learning that can guide the development and design of VR and AR applications:

- Learning is not a linear process, but an infinite, repeating cycle;
- Learning requires "here and now" experiences;
- The experiential learning cycle is best aligned with the structure and fundamental functions of the human brain;
- The foundation of learning lies in motivation — on one hand, to acquire concrete sensory experiences, and on the other, to develop abstract conceptual thinking;
- Throughout the learning cycle, the instructor shifts between different roles (facilitator, expert, assessor, coach) depending on the stage and objectives of the learning process [15,16].

By using simulation in virtual environments, learners gain the opportunity to experience situations comparable to real-world conditions, but with reduced risk and minimal potential for harm [17].

One example of immersive driver training is the VISTA-Sim project [19]. This project is being used to train professional drivers in maneuvering heavy goods vehicles (trailer trucks) using various driving scenarios developed for logistics companies [19]. The system's overall functionality can be described as follows: the user (driver) wears a VR headset that simulates the driver's view from inside the vehicle cabin. Data is collected at a central distribution point where a parking scenario at a loading bay is simulated. A physical steering wheel is also used, enabling realistic execution of maneuvers within the virtual environment.

In conclusion, we can see that the use of modern, innovative technologies in driver training represents one of the most effective solutions for developing safe vehicle operation skills. Among the key aspects, it is essential to emphasize not only that drivers acquire high-level technical competence, but also that they undergo psychological preparation for various extreme and critical situations.

CONCLUSION AND RECOMMENDATIONS

An analysis of research dedicated to the use of modern innovative technologies in addressing driver-related road safety challenges indicates a growing emphasis on psychological preparation tools for drivers, alongside technical skill development. Today, the focus is shifting toward holistic training approaches that enhance not only operational competence but also cognitive and emotional readiness for real-world driving conditions.

Technologies incorporating Virtual Reality (VR) and Augmented Reality (AR) applications are increasingly becoming integral components of driver education environments aimed at improving driving skills and correcting errors made during vehicle operation. Studies in this field demonstrate the effectiveness of digital tools in fostering immersive learning experiences. Importantly, these technologies support not only the development of vehicle control skills, but also the formation of reflective competencies — enabling drivers to understand, evaluate, and learn from their driving experiences.

In contemporary psychology, research on the implementation and application of innovative technologies for promoting safe road behavior has become highly relevant. This trend is driven, on one hand, by the rapid integration of digital innovations into everyday life, and on the other, by the urgent need to address serious societal challenges — particularly, the reduction of road traffic incidents — through evidence-based, effective technological solutions.

The adoption of various innovative technologies significantly contributes to preventing road traffic incidents and supports the development of new training practices, such as immersive driver training using VR and AR applications. These approaches enable realistic, risk-free simulation of complex and hazardous traffic situations, allowing drivers to gain experience in a controlled environment.

It is worth emphasizing that the use of innovative technologies opens up promising pathways for developing novel solutions in the field of road safety. They allow for personalized, adaptive, and data-driven training, enhancing both the quality and effectiveness of driver education.

In summary, technology plays a central role in modern driver education, enriching the learning process and equipping learners with the essential knowledge and skills needed to become safe and responsible road users. The training technologies we recommend represent cutting-edge tools that provide our learners with the most effective and comprehensive guidance for vehicle operation.

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Analysis of decision-making systems in urban road pavement maintenance

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ABSTRACT

This article analyses the issue of decision-making systems in the use of urban road pavements. In order to improve the efficiency of road maintenance and service provision and to determine the correct type of treatment of urban roads , various decision-making systems are analyzed, the main aspects of assessing the condition of the road pavement and implementing appropriate measures are highlighted. The study shows the advantages of a data-based approach to pavement management in urban road network, studies foreign experience and analyzes the extent to which this system works abroad. In addition, the article also discusses the factors that are important in the selection of continuous monitoring of road conditions, the correct choice of the type of repair, and analyzes the economic aspects of reducing operating costs. It also

highlights the indicators of achieving economic efficiency by correctly selecting the most appropriate of various types of treatments in the urban road network pavement management system. The findings have important implications for effective road infrastructure management and future planning processes.

Keywords: urban roads, decision-making system, road maintenance, urban road pavement, urban road network.

INTRODUCTION

The organization of the correct implementation of road construction and repair work is one of the most important topics today. As a result of processing the data received from each section, operational decisions are made, that is, which type of repair to perform, in many foreign countries, through automated systems. The correct choice of the repair type is the most important factor for the efficiency and economic performance of the road, since the wrong decision is likely to lead to excessive economic costs and a negative impact on the serviceability of the road network. Therefore, in order for the correct choice of the repair type in the road sector to lead to all-round efficiency, engineers in many foreign countries are conducting scientific research on this. It was compared the newly developed decision-making system for road network operations and highlighted which work to perform based on the time frame from the last road repair of urban road network. [1]

LITERATURE REVIEW.

From the moment a road is put into operation, it can lose its serviceability at any time. The primary reason for this is the impact of vehicles traveling on the road. Additionally, before carrying out road maintenance work, all relevant data must be thoroughly analyzed. In this process, properly establishing a decision-making system for road operation is of utmost importance. [2]

The key factor in developing a decision-making system is the process of collecting all relevant data on the designated road.

For effective management of pavement conditions in road operation, primary data should include road condition indicators, costs, road construction and maintenance history, as well as traffic load. To determine and assess pavement conditions and identify the causes of deterioration, a fast, cost-effective, and easily repeatable pavement evaluation system needs to be developed.

This data collection process includes the following components:

1. Road network information
2. The number and classification of vehicles traveling on the road
3. The dates of the most recent maintenance work performed
4. The expenses incurred by passengers during their journeys on the road. [3]

Collecting data on the road network involves studying selected road sections. It is also important to consider the function of the road being studied, as it may have either a primary or secondary significance within the network.

Traffic intensity should be measured using the most accurate method available and categorized by vehicle type. This indicator is crucial for road assessment. The number of vehicles passing through the selected area is a key factor in the analysis.

The date of the last maintenance work on the road is also essential for making informed decisions. It is important to consider how the previous repair was carried out. If it was a major reconstruction, the base layer is likely to be sufficiently strong, and working on the pavement surface may be sufficient for this section.

Planned maintenance processes were traditionally carried out every five years as either major or routine repairs. However, selecting the wrong type of repair can lead to economic inefficiencies and cause the repaired road section to be out of service for a certain period. [4]

Improving the pavement management system is not just about implementing a new system—it can also lead to significant economic benefits. The time elapsed after a major or routine repair directly impacts the deterioration of road quality. The worse the condition of the road becomes, the higher the cost required to restore and maintain it.

To prevent this situation, it is crucial to conduct frequent rehabilitation work, ensuring that the road remains in good serviceable condition before it reaches a critical state.

Organizing proper pavement condition management means making informed decisions based on data collected about the road's condition. Selecting the correct timing and type of maintenance ensures that the road remains in good condition for a longer period. [5]

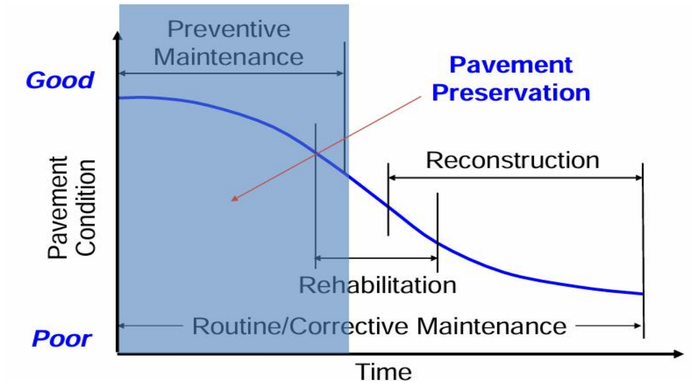

Figure 1. Measures taken to maintain the coating in a uniform condition. [6]

It is extremely important to regularly observe and assess the condition of pavements to ensure they remain in good shape (Figure 1). By doing so, road authorities or maintenance teams can make timely and well-informed decisions regarding what kind of maintenance or rehabilitation actions need to be taken. These decisions should be supported by a well-functioning and efficient decision-making system, which helps in prioritizing actions based on the actual needs of the pavement. [6]

If pavement conditions are not monitored or addressed in time, they may continue to deteriorate until they reach a point where simple maintenance is no longer effective or possible. In such cases, the pavement may fall below the acceptable maintenance threshold—the point beyond which more intensive and costly repairs are required. To avoid this, it is crucial to properly implement the steps involved in the "Rehabilitation Process", as illustrated in the accompanying graphic. This process includes identifying the right time for intervention and applying the right type of rehabilitation treatment based on the pavement's condition. [7]

By following this proactive and systematic approach, it becomes possible to preserve the pavement's serviceability and quality over time, without having to resort to full reconstruction, which is usually much more expensive and time-consuming. The system described below provides a structured framework or guideline that can help decision-makers select the most suitable type of maintenance or rehabilitation and determine the best timing for its implementation, ensuring long-term performance and cost-efficiency. [8]

The foundation of the decision-making system has been developed by researchers at Caltrans University in the state of California as follows.

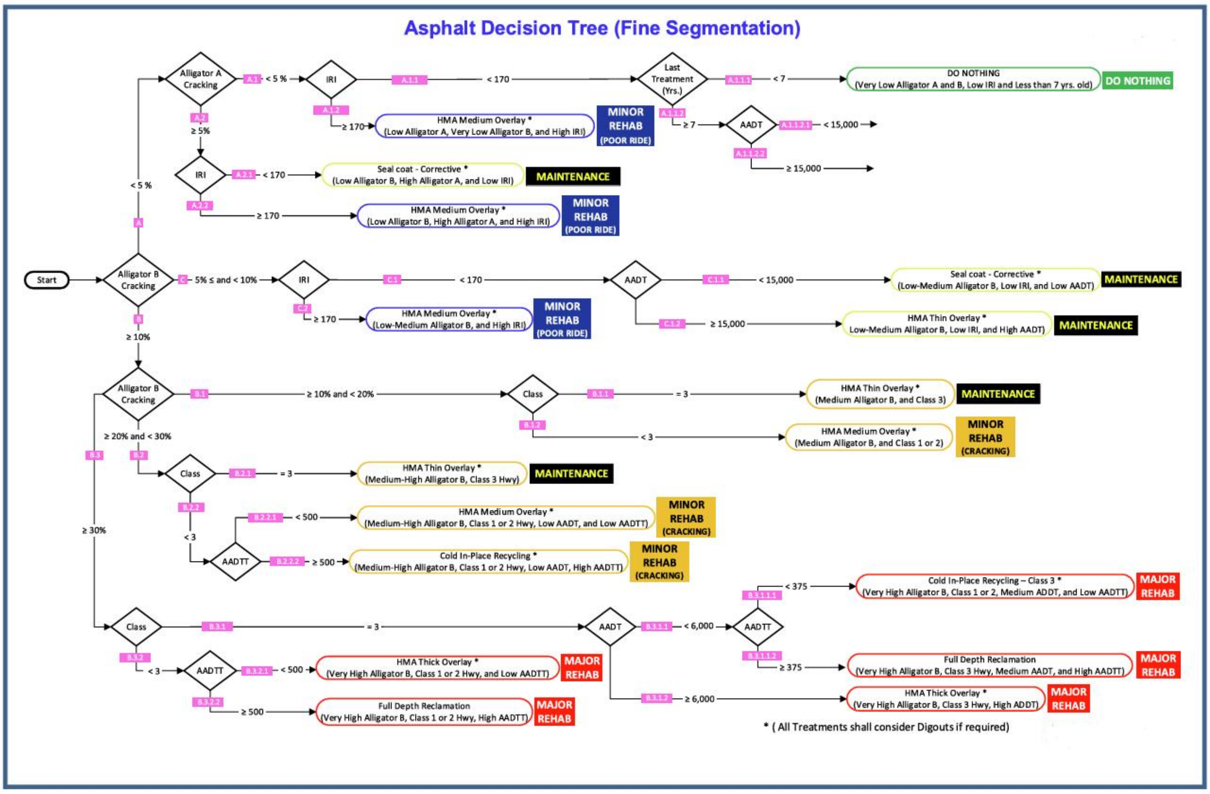

Figure 2. Decision trees for asphalt pavements. ***[3]***

The decision tree allows you to analyze all the information obtained from the road surface that needs to be worked on and determine what type of work should be carried out for this object. This system works by connecting all the information. When it is able to clearly combine the sequence of data, it produces the final result based on what type of work should be performed. Each branch of the decision tree is for exactly one type of repair. This decision-making system for the operation of road surfaces in urban areas was developed by engineers at the Caltrans Research Center for both AC (asphalt concrete) and JPCP (jointed plain concrete pavements) pavements. Figs 2–3. Through this system, the condition of roads across the network can be assessed, categorized, and marked with colors (as shown in Figure-1 and Figure 2). Road sections in good condition can be left as they are, while primary maintenance efforts should focus on areas that have deteriorated into the red zone, indicating urgent repair needs. **[3]**

Asphalt Decision Tree for Urban Road Maintenance

This decision tree provides a structured approach for determining the appropriate maintenance or rehabilitation strategy for asphalt roads based on various factors, including pavement condition, roughness, traffic volume, and previous maintenance history. **[9]**

Key Factors Considered in the Decision Tree:

1. Alligator B Cracking Percentage – Measures the extent of cracking in the pavement.
2. IRI (International Roughness Index) – Indicates the smoothness of the road surface.
3. AADT (Average Annual Daily Traffic) – Represents the daily traffic load on the road.
4. Road Classification (Class) – Categorizes the road based on traffic density.
5. Previous Maintenance – Considers the last time maintenance was performed.

Decision Tree Process:

Initial Assessment

The process begins by evaluating the percentage of Alligator B cracking on the pavement.

If the cracking is less than 5%, the IRI (smoothness index) is checked.

If the cracking is greater than 5%, further analysis is required.

Evaluating IRI (Smoothness Index)

IRI < 170 (inches/mile=2.6 m/km): The road is still relatively smooth, requiring only minor repairs or maintenance.

IRI ≥ 170 (inches/mile=2.6 m/km): The road has noticeable roughness, possibly requiring more significant treatment.

Assessing Traffic Volume (AADT)

AADT < 15,000: Roads with lower traffic loads may require less extensive repairs.

AADT ≥ 15,000: Roads with heavy traffic may need more durable rehabilitation.

Determining the Appropriate Treatment:

DO NOTHING

If cracking is less than 5%, IRI < 170 (inches/mile=2.6 m/km), and the last treatment was within 7 years, no maintenance is required.

Conditions: Very low cracking, low IRI, and recent maintenance.

Reasoning: The road is still in good condition and does not require immediate intervention.

PREVENTIVE

Low Cracking Levels (Alligator B < 5%)

If the road has very few cracks and an IRI < 170 (inches/mile=2.6 m/km), it is still in good shape.

If more time has passed, preventive maintenance may be applied to slow down deterioration.

Mild Cracking (5% ≤ Alligator B < 10%)

Moderate Cracking (10% ≤ Alligator B < 20%)

At this stage, preventive maintenance can still be used, but minor rehabilitation may be necessary.

MAINTENANCE (Routine Preservation)

Involves light maintenance treatments to extend pavement life.

Examples:

Seal Coat - Corrective: For roads with minimal traffic and low cracking.

HMA Thin Overlay: For roads with moderate cracking and traffic.

Applied when:

Alligator B cracking is between 5% and 10%.

IRI < 170 (inches/mile=2.6 m/km), and AADT (Average Annual Daily Traffic) is relatively low.

MINOR REHAB (Moderate Repairs)

Used for roads with moderate cracking and roughness issues.

Examples:

HMA Medium Overlay: Based on cracking percentage and AADT (Average Annual Daily Traffic).

Cold In-Place Recycling: Used if moderate cracking is combined with poor traffic conditions.

Applied when:

Cracking is between 10% and 30%.

IRI ≥ 170 (inches/mile=2.6 m/km), or the pavement exhibits significant wear.

MAJOR REHAB (Full Reconstruction or Deep Repairs)

Applied to severely damaged roads.

Examples:

HMA Thick Overlay: If cracking is severe.

Full Depth Reclamation: When the pavement requires complete reconstruction.

Applied when:

Cracking exceeds 30%.

AADT (Average Annual Daily Traffic) is very high.

IRI is extremely poor, indicating heavy structural deterioration.

Practical Implications:

This decision tree helps optimize urban road maintenance by:

Reducing repair costs through timely intervention.

Allocating resources efficiently.

Extending pavement lifespan.

Improving road safety and ride quality. [10]

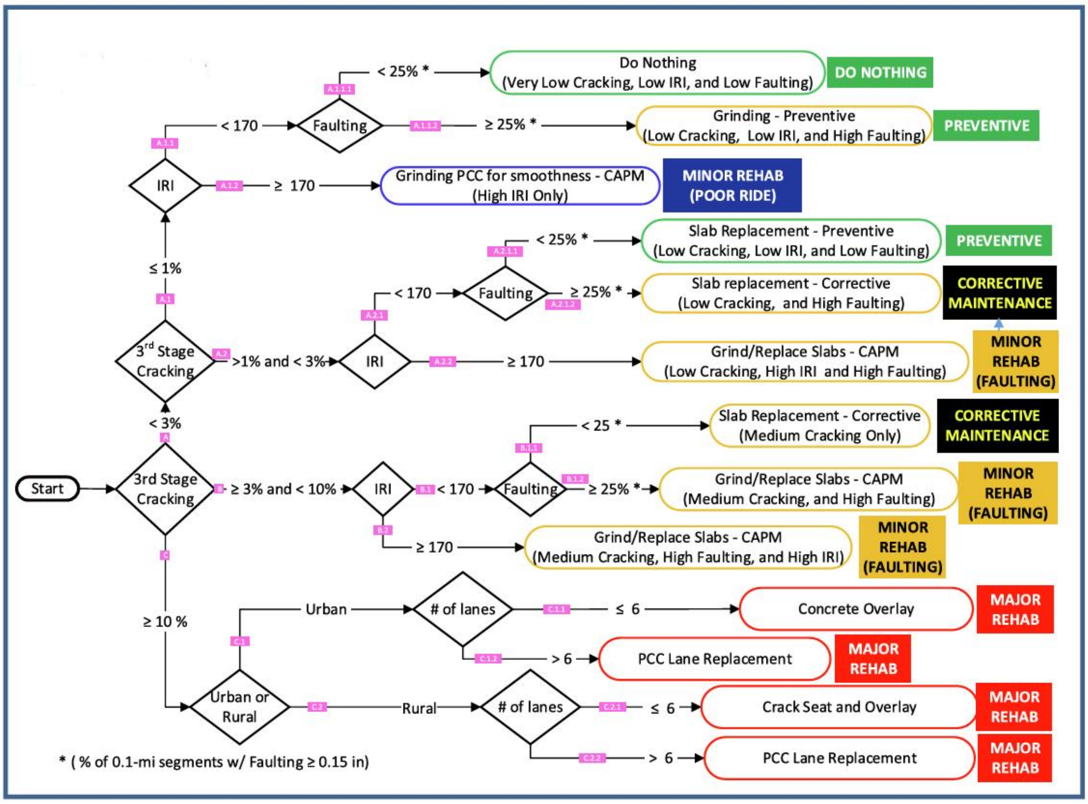

Figure 3. Decision trees for jointed plain concrete pavements **[2].**

This decision tree is used for Pavement Maintenance and Rehabilitation Decision-Making. It considers different pavement conditions (cracking, roughness, and faulting) and suggests appropriate maintenance or repair methods **[**2**].**

Step 1: Start with Third-Stage Cracking

The first step in the decision tree is assessing third-stage cracking, which is severe cracking that affects the pavement's structural integrity.

- If cracking is ≤1%, the pavement is in good condition, and we proceed to check other factors like roughness (IRI) and faulting.

- If cracking is between 1% and 3%, the pavement has minor issues, and we move forward in the decision process.
- If cracking is between 3% and 10%, it is considered medium-level damage.
- If cracking is ≥10%, the pavement is in poor condition, requiring major rehabilitation.

Step 2: Assess IRI (International Roughness Index)

The IRI is a measure of road smoothness:

- Low IRI (<170) (inches/mile=2.6 m/km) means the pavement is relatively smooth.
- High IRI (≥170) (inches/mile=2.6 m/km) indicates a rough ride, possibly needing rehabilitation.

Step 3: Check Faulting

Faulting refers to vertical displacement at pavement joints, causing bumps in the road. If faulting is ≥25%, it means significant surface distress.

Step 4: Apply Maintenance or Rehabilitation

The decision tree suggests different types of maintenance or rehabilitation based on these conditions:

1. If there is very little damage (≤1% cracking, low IRI, low faulting)

Do Nothing (Green) → The pavement is in good condition.

2. If there is minor damage (Low Cracking, Low IRI, but High Faulting)

Preventive Maintenance (Light Green)

- Grinding - Preventive: Used when there is low cracking and faulting.

Minor Rehabilitation (Poor Ride) (Blue)

- Grinding for Smoothness - CAPM: Used when IRI is high (meaning the pavement ride is rough), but other damage is minimal.

3. If there is moderate damage (1-10% Cracking, Medium Roughness, or High Faulting)

Corrective Maintenance (Yellow)

- Slab Replacement - Preventive: If faulting is low.
- Slab Replacement - Corrective: If faulting is high.
- Grind/Replace Slabs - CAPM: Used if cracking and roughness are both moderate.

Minor Rehabilitation (Faulting) (Dark Yellow)

- Used when medium cracking and faulting are both present.

4. If the pavement is severely damaged (≥10% Cracking)

Major Rehabilitation (Red)

- Concrete Overlay: Used for urban roads with ≤6 lanes.
- PCC Lane Replacement: Used for urban roads with >6 lanes.
- Crack Seat and Overlay: Used for rural roads with ≤6 lanes.
- PCC Lane Replacement: Used for rural roads with >6 lanes.

Key remedies

- Low Damage → No Action or Preventive Maintenance
- Moderate Damage → Minor or Corrective Repairs
- High Damage → Full Rehabilitation (Expensive & Intensive Repairs)

Each condition of pavement damage leads to a different action based on roughness, faulting, and the extent of cracking. This structured approach helps decide the most cost-effective and appropriate repair strategy for maintaining roads efficiently. **[11]**

During the operation of the pavement, the engineer's task is to carefully approach the schedules and each element of the project. The main content of this task is to develop an algorithm for timely execution of the most important and necessary repair works in order to maintain the condition of the city's road network in working condition and extend its service life, and to develop a decision tree to standardize this system and increase the efficiency of the city's highways.

For this, one of the main factors is to find the share of the road length allocated for each repair.

• If we take the length of the object marked in red for **rehabilitation effectiveness**, then its percentage share of the total road length will be attributed to this type of repair (1).

• For **CAMP Effectiveness**, the share of the object is taken as the ratio of the areas of the object marked in (red + orange) to the total length, also in percentages (2).

• The amount of **maintenance effectiveness** is determined in the same way as above, calculated as the ratio of the length of the object marked in yellow to the total length of the object (3).

To determine the overall effectiveness of this project, it is possible to check how effective the quality of the project is by researching the condition of the Pavement **[**12**]** **[**13**]**.

$$Rehabilitation\ Effectivenss = \frac{Red\ Lane\ Miles}{Total\ project\ line} * 100\% \qquad (1) \qquad [2]$$

$$CAPM\ Effectivenss = \frac{(Red+Orange)\ \ Lane\ Miles}{Total\ project\ line} * 100\% \qquad (2) \qquad [2]$$

$$Maintenance\ Effectivenss = \frac{Yellow\ Lane\ Miles}{Total\ project\ line} * 100\% \qquad (3)\ [2]$$

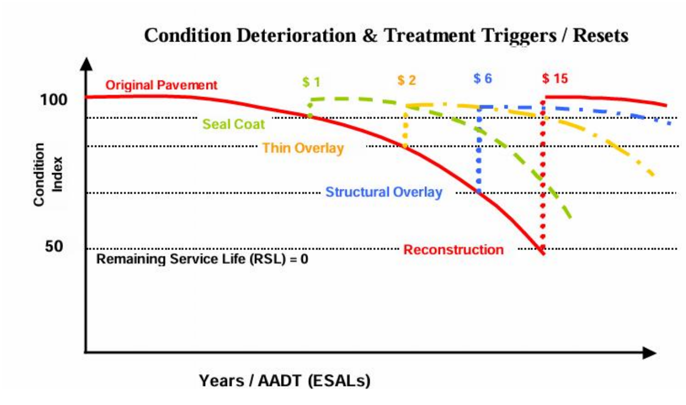

Figure 4. Relationship between condition of pavement and cost effective [13].

Over time, the performance of all pavements decreases, which leads to an increase in the cost of repairing this road. As we can see in the graph above, the more the condition of the pavement deteriorates, the more the economic cost increases. Figure 4.

To prevent this, it is necessary to constantly monitor the condition of the road and determine what needs to be done in a timely manner and carry out this work at the facility.

Currently, the following system is used to determine the type of repair in the operation of highways. The main factor of this system is transport operational indicators. In this case, the condition of the road is studied through 4 indicators and the type of repair is determined. Depending on the condition of the object under study, separate works can be carried out in separate sections. Fig.5

The work is carried out based on the data on the indicators of smoothness, bite coefficient, calculated speed provision coefficient, and relative fatality coefficient and is analyzed as follows[14]:

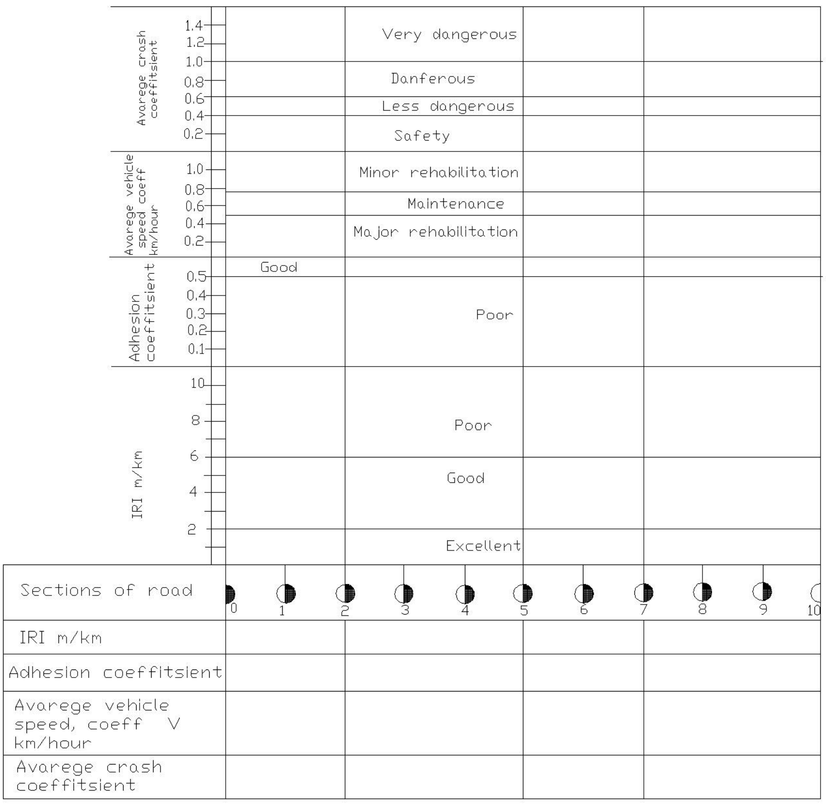

Figure 5. The system of detecting type of construction by transport operational indicators [14].

By evaluating these transport and operational indicators, the condition of the road is determined and the accident coefficient of the road section is determined.

$$K_a = \frac{Z \bullet 10^6}{365 \bullet N \bullet L_{уч} \bullet n}$$

(4) **[14]**.

here:

Z-number of car accidents; N-daily traffic , vec/hour; Range –length of area, km; n- years. Range • n The normal of average crash coeffitsient:

Ка < 0,40 safety;

Ка - 0,40÷0,80 less dangerous;

Ка -0,80 ÷1,2 dangerous;

Ка >1,2 very dangerous

Roughness

S=>6 м/км poor condition

S=2-6 м/км good condition

S= < 2 м/км excellent

Normal adhesion coeffitsient:

wet condition φ=0,40

Dry condition φ=0,45

If vehicle real speed less than design speed this method was:

Кn.s= Кreal/ Кdesign;

0,5- minor rehabilitation;

0,5-0,75 -maintenance;

0,75-1,0 -major rehabilitation.

Although this system is currently working, it has some shortcomings, as it takes into account operational indicators when determining the type of repair, but the work to be performed is determined solely based on the calculated speed **[**14**]**.

LESSONS LEARNED AND PREDICTION PAVEMENT SERVICE ABILITY

The problem that can be observed in the development of a decision-making system for pavement operation is that when this system is created through programs, does the contribution of the human factor decrease? - By implementing a decision-making system for the operation of road pavements in the city, the system takes on a number of tasks that engineers should perform and somewhat reduces the work performed by the human factor, which does not mean that it will be a full-fledged system, because a person will constantly take control of it and a person will definitely have to correct errors in the system without delay and enter new information and tasks into it. On the one hand, when automating this system, it can work several times faster and more accurately than a person, which somewhat simplifies the road network in the city, but politically and strategically it cannot replace a person.

In recent years, the improvement of road pavement management systems has been rapidly growing, and special programs are the best helper in this. The basis for the automation of each system is its proper organization. Improving the decision-making system in the operation of urban road pavements is a key link in the pavement management system. Based on the research of engineers at the Caltrans Research Center in California, the economic indicator of the decision-making system is estimated at $ 20 billion over the next decade. This project focuses mainly on the future performance of the pavement.

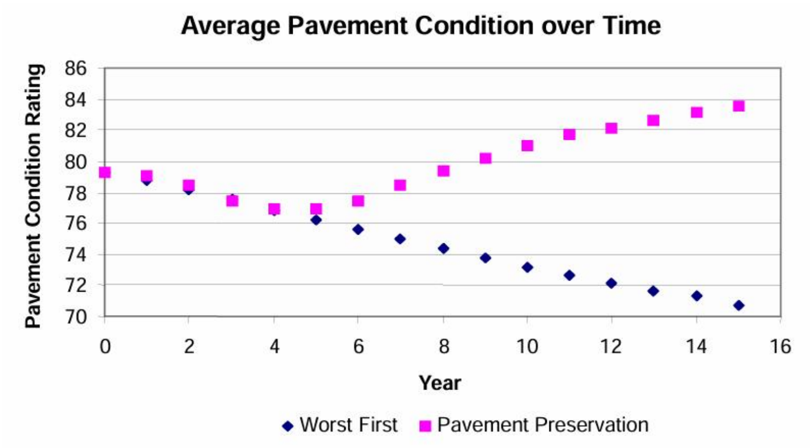

Figure 6. Average Pavement Condition over time [13].

This chart illustrates the impact of two different pavement management strategies—**"Worst First"** and **"Pavement Preservation"**—on the average pavement condition rating over time.

Key remedies for Urban Road Pavement Management:

1. Worst First Approach (Blue Diamonds)
   - This method prioritizes repairing the worst roads first.
   - The graph shows that under this approach, the overall pavement condition rating declines over time.
   - This happens because waiting for roads to deteriorate before fixing them leads to more extensive and expensive repairs, allowing the overall network condition to degrade.
2. Pavement Preservation Approach (Pink Squares)
   - This strategy focuses on maintaining roads in good condition through timely, less expensive maintenance.
   - Over time, the graph shows an increase in pavement condition ratings.
   - Preventive maintenance (e.g., crack sealing, resurfacing) extends pavement life and keeps roads in better shape for longer.

Urban Road Management Implications:

- A "Worst First" strategy may seem logical but results in declining road conditions and higher long-term costs.
- A Pavement Preservation approach maintains roads at a higher quality, reducing overall deterioration and costs.
- Cities should invest in preventive maintenance rather than waiting for roads to fail.

Currently, the key factors in the decision-making system for road maintenance in Uzbekistan include road smoothness, adhesion coefficient, design speed, and the accident rate in recent years. **[**14**]**.

The International Roughness Index (IRI) is an internationally recognized measurement standard for assessing the roughness of a road surface (m/km). Various modern methods are currently being used to determine the IRI. The value of the IRI increases with the roughness of the surface; the more uneven the surface, the greater the IRI value.**[**15**]**

The required value range of the International Roughness Index (IRI) for determining pavement condition:

- **0-2:** Excellent condition
- **3:** Good condition
- **4-5:** Satisfactory (minor surface repairs needed)
- **6-7:** Requires repair (potholes present, patching needed, and some areas may require resurfacing)
- **8+:** Very poor condition (resurfacing required). **[16]**

The **adhesion coefficient** in road-transport engineering is a physical parameter that represents the level of friction between vehicle tires and the road surface. This coefficient plays a crucial role in determining the efficiency of **braking, acceleration, and vehicle control**.(5)

It is commonly denoted by the Greek letter **μ (mu)** and is defined as the ratio of the **maximum friction force** between the tire and the road surface to the **normal force** exerted by the tires:

$$\mu = \frac{Ffriction}{Fnormal} \qquad (5) \qquad [16]$$

Ffriction= Friction force

Fnormal=Normal force exerted by the tires on the road surface (axle load). **[17]- [18]**

PAVEMENT STRENGTH AND DESIGN SPEED UTILIZATION COEFFICIENT (6)

Pavement Strength refers to the road's ability to withstand heavy loads and external impacts, ensuring its long-term durability. To maintain pavement strength, factors such as structural design, material quality, and operational conditions must be considered [16**].**

Design Speed Utilization Coefficient is an operational parameter that evaluates how well a road segment allows vehicles to reach their design speed. It is determined by the ratio of a vehicle's actual maximum achievable speed on a given road section

Vh.max (considering road safety and vehicle-road interaction conditions) to the design speed for that road category and terrain Vh.calculated:

$$V = \frac{V(max)}{V(designed\ speed)} \quad (6) \qquad [16]$$

The Design Speed Utilization Coefficient is defined as the ratio of the actual maximum achievable speed (Vmax) on a given road section to the design speed (Vdesigned speed) set for that road category and terrain:

Where:

- V — Design Speed Utilization Coefficient
- Vmax— Actual maximum achievable speed on the road section
- Vdesigned speed— Designed speed for the road category and terrain

This coefficient helps evaluate whether a road segment allows vehicles to travel at the intended design speed, considering safety and road conditions.[19]- [20]

The importance of maintaining an accurate project database cannot be overstated. Information from past projects forms the foundation for predicting the performance of future ones. Meanwhile, current and upcoming projects—especially those that are officially designated or mandated—must be completed before the PaveM system can be used to identify any additional projects. If there are inaccuracies in this list of required projects, it can disrupt the entire delivery plan.

Keeping project data up to date is a regular responsibility. To reduce repetitive manual data entry, efforts are being made to allow data to be shared between project databases. Automating this process will also help ensure the data is accurate and consistent. There have been suggestions to decentralize this task by having district personnel update their own project information directly in the system. However, involving more people in maintaining the same data could lead to challenges in managing data quality. For this reason, **Caltrans has decided to retain central control of the PaveM system** to better ensure data consistency and reliability.

THE VALUE OF PROACTIVE PAVEMENT MANAGEMENT

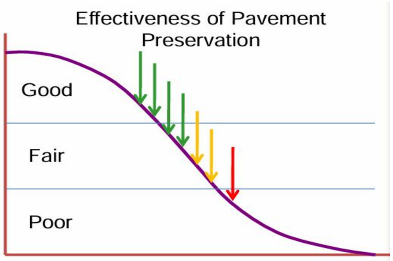

Figure 7. Effectiveness of Pavement Preservation ***[13].***

The image highlights a key principle in pavement management: preservation is most effective when it's done early—before roads fall into poor condition. This concept is visualized in the graph, which shows the effectiveness of pavement preservation treatments over time as pavement condition declines from *Good* to *Poor*.

What the Graph Shows:

- The curve represents the natural deterioration of pavement over time if no maintenance is performed.
- The colored arrows indicate when different types of preservation treatments can be applied:
- Green arrows (in Good condition) show early interventions that are highly cost-effective. These might include preventive maintenance such as crack sealing or surface treatments.
- Yellow arrows (in Fair condition) represent treatments that are still helpful, but less effective than early fixes.
- Red arrows (in Poor condition) point to late-stage repairs or complete reconstruction—these are far more expensive and less efficient.

Key solutions from the Slide:

- Be Proactive: Investing in maintenance while the road is still in good condition can prevent major deterioration and reduce long-term costs.

- Prevent Decline: The goal is to keep roads from slipping into poor condition, where repairs become more complex and costly.
- Use a Mix of Fixes: A successful pavement management program doesn't rely on one type of treatment. It incorporates a variety of fixes tailored to pavement conditions and timing.
- Pavement Management Systems (PMS): These systems help agencies determine what treatments to apply and when they will be most cost-effective, based on pavement performance models.

In summary, the graph and points together promote a data-driven, proactive approach to infrastructure maintenance. With strategic planning and timely action, agencies can stretch limited budgets further while maintaining better roads for the public. [21]

COMPARISON OF VARIOUS BUDGET SCENERIES

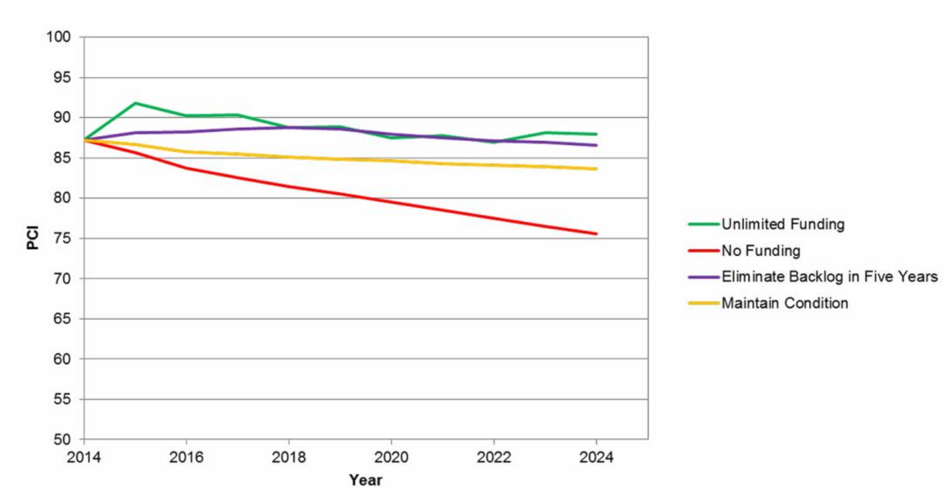

Figure 8. Compares various budget sceneries [21].

Pavement Condition vs. Funding Scenarios: What This Graph Tells Us About Cost-Effective Urban Road Management

This chart visualizes how different funding strategies affect the long-term condition of urban pavements, using the Pavement Condition Index (PCI) as a performance measure. The PCI ranges from 0 (failed) to 100 (perfect), and values above 85 typically indicate good condition.

Breakdown of Funding Scenarios:

Green Line – Unlimited Funding: Under this ideal scenario, all pavement needs are addressed immediately. As a result, the PCI remains consistently high (above 90). While this strategy ensures excellent conditions, it is often unrealistic for cities with budget constraints. However, it demonstrates the potential of a fully funded, proactive maintenance strategy.

Red Line – No Funding: This shows the cost of inaction. With no investment in maintenance or repair, the PCI steadily declines—from around 86 in 2014 to about 75 in 2024. As conditions worsen, future repairs become significantly more expensive, since more roads will require major rehabilitation or reconstruction instead of lower-cost preventive maintenance.

Purple Line – Eliminate Backlog in Five Years: This represents a strategic investment approach where funding is focused on clearing deferred maintenance and overdue repairs over a five-year period. The PCI improves slightly and remains stable over time. While more realistic than unlimited funding, it still requires a strong, time-limited financial commitment, but results in sustained improvement [22].

Yellow Line – Maintain Condition: This is often the most cost-effective strategy for urban pavement management. The goal here is to invest just enough to preserve current pavement conditions, avoiding major deterioration. The PCI remains steady around 85, preventing roads from falling into the "poor" range while minimizing expensive reconstructions in the future. [22]

Key Insights for Urban Pavement Managers:

1. Proactive Investment Saves Money:
   Preventive maintenance is far cheaper than reconstructing deteriorated roads. The sooner an issue is addressed, the lower the cost.
2. "Do Nothing" is the Most Expensive in the Long Run:
   The red line highlights how quickly pavement can degrade without funding, leading to higher future rehabilitation costs and poorer road user experience.

3. Balanced Funding is Best:

   While unlimited funding isn't practical, strategies like backlog elimination or condition maintenance offer sustainable, cost-effective solutions for urban road networks.

4. Pavement Management Systems (PMS) are Essential:

   A well-implemented PMS can help city planners determine where, when, and how much to invest in roads—maximizing value from limited budgets.[23]

CONCLUSION

In summary, a robust road management decision-making system ensures greater cost-efficiency, enhances transportation performance, improves road safety, reduces environmental impact, and strengthens the ability to plan and manage infrastructure sustainably over the long term.

This article analyzes the decision-making systems in highway operation in several developed countries around the world. In this case, the interdependence of transport operational indicators, which is the most important in determining the type of repair, is of great importance.

In the system described above, the main indicator for choosing the type of repair is the level of relative speed, while in order to make the decision-making system more accurate, we need to create a system that closely links all operational indicators, based on the system created by researchers at Caltrans University.

ACKNOWLEDGMENT

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The use of a driving simulator to improve education in traffic engineering

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ABSTRACT

The article examines the potential use of driving simulators in the educational process of training specialists in the transport sector. It analyzes the possibilities of using simulators for teaching traffic rules, the fundamentals of traffic safety, as well as the methodology for training, retraining, and professional development of drivers. The potential benefits of integrating driving simulators into educational programs are discussed, including the development of practical skills, improvement in the assimilation of theoretical knowledge, and the formation of professional competencies in students. The article highlights the need for further research to assess the effectiveness of using driving simulators in the training of transport specialists.

Keywords: driving simulator; driver training; road safety; simulation technologies; transport engineering; sustainable transport; educational innovation; sustainable development; driving simulation

INTRODUCTION

Modern education in the field of transport engineering places increasingly high demands on the quality of training for specialists capable of working effectively in the context of rapidly developing technologies and growing risks on the roads. Traditional teaching methods, primarily based on lectures and limited driving practice, often prove insufficient for the comprehensive development of students' professional skills. In this regard, the use of simulation technologies, particularly driving simulators, is gaining increasing importance, as they allow for the modeling of a wide range of road situations and conditions within a safe virtual environment.

The use of driving simulators as a tool for engineering and professional training is thoroughly described in the works of Fisher et al. (2011), which examine various types of simulators, simulation scenarios, and methods for assessing driver behavior in a controlled environment.[1]

The aim of this article is to describe the potential applications of driving simulators in the education of transport-related students and to analyze the possible advantages of integrating such technologies into the educational process.

METHODS

The article is based on descriptive and analytical approaches, including the study of foreign literature, a description of the technical characteristics of a driving simulator, and an analysis of its potential integration into the educational process for training specialists in the transport sector. During the research, publications on the use of driving simulators in the education of transport-related students were analyzed, along with the advantages of using simulation technologies for developing the professional competencies of drivers and engineers.

A comprehensive analysis of simulation-based training systems is presented in the work by Zhao et al. (2018), which examines the principles of simulator design, their classification, and their effectiveness in education. [2]

The technical basis under consideration includes driving simulators equipped with an instrument panel featuring a steering wheel, turn signal lever, windshield wiper lever, accelerator, brake, and transmission pedals, a gear shift, a parking brake, as well as driving simulation software. This software enables the modeling of various road situations, traffic conditions, terrain types, time of day, weather factors, and the behavior of other drivers and pedestrians. The simulator can also be equipped with VR goggles and a dynamic multi-axis motion platform, which create a fully immersive virtual environment and enhance the realism of the driving experience. Such equipment allows for the customization of training scenarios depending on the specific learning objectives.

Figure 1. External view of the driving simulator

European experience confirms the high effectiveness of using simulators in educational institutions and driving schools (European Commission, 2016). [3] The methodological foundations of simulation-based learning, including its advantages for developing sustainable skills, are examined in the work of Lateef (2010). [4]

RESULTS

As a result of the literature review and the generalization of practical experience with the use of driving simulators in the educational process, key areas were identified in which the use of such equipment contributes to improving the quality of training for transport-related students. Firstly, the use of a driving simulator in the course "Traffic Rules" significantly enhances the assimilation of theoretical knowledge by reinforcing it in conditions close to real-life situations. Simulating road scenarios in the simulator helps students develop skills in the correct application of traffic regulations, recognition of road signs and traffic signals, understanding of right-of-way rules, and practicing vehicle stopping and parking. Practical sessions on the simulator increase students' confidence and reduce the number of mistakes made in real traffic environments. Secondly, in the course "Fundamentals of Traffic Safety," the driving simulator plays an important role in developing professional skills aimed at preventing road traffic accidents. The simulator enables practice in safe starting, lane changing, maintaining optimal distance and lateral clearance. Especially important is the ability to train driver reaction times to sudden changes in road conditions, such as abrupt braking of the vehicle ahead, the appearance of obstacles, or changes in traffic lights. In addition, the simulator allows for driving in challenging weather and road conditions (fog, ice, off-road), which cannot be safely practiced in traditional training without risking students' health or damaging vehicles.

Thirdly, in the course "Methodology for Training, Retraining, and Advanced Training of Drivers," the use of a driving simulator allows for the preparation of future instructors and methodologists with a high level of professional competence. Students not only learn driver training techniques but also practice demonstrating typical and emergency situations, and simulate various road scenarios in order to develop their own methodological approaches. This approach fosters the formation of systemic thinking, the ability to analyze and predict road situations, and enhances the readiness of future instructors to conduct driver training at a qualitatively new level.

Figure 2. Driving simulation in urban areas and on a training ground

The use of a driving simulator in the educational process enhances the effectiveness of training for transport-related students, develops practical skills essential for ensuring road safety, and fosters professional competencies that meet modern requirements.

DISCUSSION

The use of driving simulators in the educational process for transport-related fields is an effective tool for developing the professional competencies of future specialists. Modern simulators enable the modeling of a wide range of road scenarios, creating conditions for indepth study of traffic rules, the development of stable safe driving skills, and the ability to make correct decisions in unusual and emergency situations.

International experience in the use of driving simulators for training drivers and transport engineers shows that such technologies are widely applied in universities and educational centers in Japan, the United States, South Korea, and other countries. In Japan, driving simulators are used in professional development programs, including the simulation of sudden road situations and the evaluation of driver reaction (Hirata et al., 2019) [5]. In South Korea, simulators are employed in the training of transport students to practice driving in metropolitan areas with high traffic density and complex road infrastructure, including the simulation of intelligent transport systems and automated control [6]. At the same time, the implementation of driving simulators into the educational process requires addressing a number of organizational and technical issues. These include the need for a qualified teaching staff capable of effectively integrating the simulator into academic programs, as well as the necessity of regularly updating software and maintaining the equipment to ensure its high functionality.

In foreign universities, driving simulators are used not only in courses similar to those described in this article, but also in areas such as:

• traffic flow management and road traffic modeling;

• research in the field of automated and autonomous transportation systems;

• psychological training of drivers to assess reaction and psychophysiological condition.

These examples demonstrate the broad potential of using driving simulators in the training of transport industry specialists and highlight the need for further research on the integration of simulation technologies into the educational process. The discussion of results shows that driving simulators are a promising tool for improving the quality of training for transport-related students, offering a combination of theoretical knowledge and practical skills, and developing competencies that meet modern safety and efficiency standards of the transportation system.

CONCLUSION

The conducted analysis has shown that driving simulators are an effective tool for enhancing the quality of training for transport-related students. Their use contributes to the reinforcement of theoretical knowledge, the development of practical safe driving skills, the formation of stable reactions to non-standard road situations, and the improvement of professional competence among future engineers, educators, and instructors.

The integration of driving simulators into the educational process offers broad opportunities for modeling various road conditions and scenarios, which cannot be fully realized within the framework of traditional training. International experience also confirms the high effectiveness of simulators both at the stage of basic education and in the advanced training of drivers and transport professionals.

A promising direction for future research is the implementation of empirical studies to assess the impact of simulator-based training on students' knowledge, skills, and practical abilities. This would provide quantitative confirmation of the effectiveness of simulator integration into the educational process and help develop scientifically grounded recommendations for their inclusion in transport specialist training programs.

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AI-Powered Sustainable Transportation: Emerging Trends, Challenges, and Future Directions

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ABSTRACT

Sustainable transport is now at the forefront of international research and policymaking due to the fast increase in urbanisation, worries about climate change, and rising demand for mobility. Advanced solutions for improving efficiency, cutting emissions, and optimising transportation systems are provided by artificial intelligence (AI). This thesis highlights the difficulties in incorporating AI algorithms into existing systems while examining new developments in sustainable transportation, such as shared mobility platforms, electric mobility, driverless cars, and smart infrastructure. Important challenges are examined critically, including data privacy, energy use, moral ramifications, and legislative frameworks. This paper offers a roadmap for how AI-powered sustainable mobility may meet societal and environmental demands worldwide by combining the most recent research.

Key words:Autonomous vehicles, shared mobility, electric mobility, artificial intelligence, carbon neutrality, and smart infrastructure are all examples of sustainable transportation.

INTRODUCTION

Achieving climate targets and lowering carbon emissions now depend on sustainable mobility. Approximately 24% of the world's CO2 emissions come from the transport sector (IEA, 2023). In this regard, artificial intelligence (AI) has become a game-changing tool that may improve productivity, optimise resource allocation, and facilitate predictive decision-making in sustainable transportation [1].

NEW DEVELOPMENTS IN ECO-FRIENDLY TRANSPORTATION

One of the pillars of sustainability is the transition from fossil fuel-powered automobiles to electric vehicles. AI-powered battery management systems (BMS) predict energy usage, prolong battery life, and optimise charging cycles. Additionally, charging station placement is enhanced by predictive algorithms to lessen range anxiety.

Road safety and less traffic are promised by autonomous cars. Real-time traffic data, pedestrian identification, and route optimisation are all processed by AI systems, particularly deep learning models. Reduced emissions and idle time are examples of sustainable advantages [2,3].

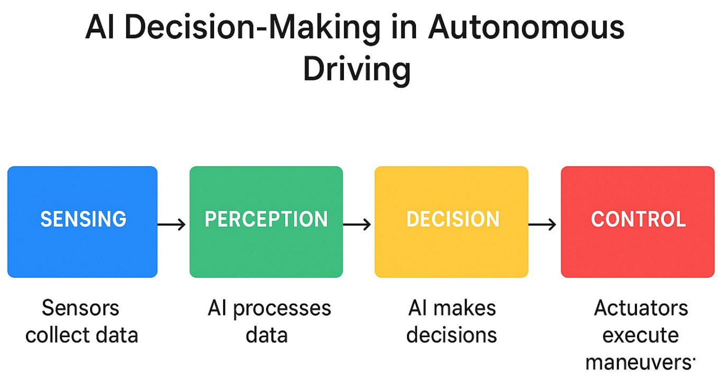

Figure 1. AI Decision-Making in Autonomous driving [4]

AI facilitates dynamic ride-sharing by effectively matching drivers and riders. Because there are fewer cars on the road, there is less traffic and pollution. Algorithms that use reinforcement learning forecast demand hotspots and dynamically modify prices.

IoT-enabled sensors and AI-powered intelligent transportation systems (ITS) are being integrated by cities. To reduce fuel usage, these technologies estimate traffic, optimise traffic signals, and offer real-time routing.

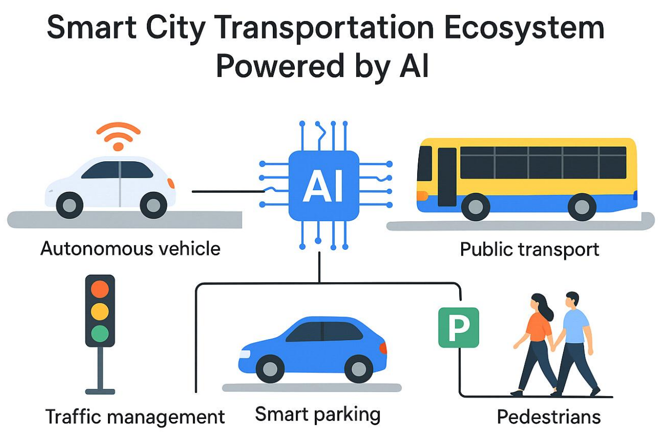

Figure 2. Smart City Transportation Ecosystem powered by AI [5]

CHALLENGES IN AI-DRIVEN TRANSPORTATION

Data Security and Privacy: Cybersecurity threats arise from large datasets of automobiles, passengers, and infrastructure.

High Energy Demand: The high processing power needed by AI algorithms may counteract any environmental benefits.

Ethical and Social Issues: In the event of an accident, autonomous decision-making presents liability issues.

Policy and Regulatory Barriers: Large-scale implementation of AI in transportation is delayed by the absence of international standards.

Infrastructure Gaps: Due to a lack of funding, developing nations find it difficult to implement AI-enabled transportation.

PROSPECTIVE PATHS

International legislative frameworks, federated learning for privacy, and AI computing driven by renewable energy sources can all help to lessen difficulties. For AI-driven transport systems to be sustainable and egalitarian, cooperation between academia, industry, and policymakers is crucial.

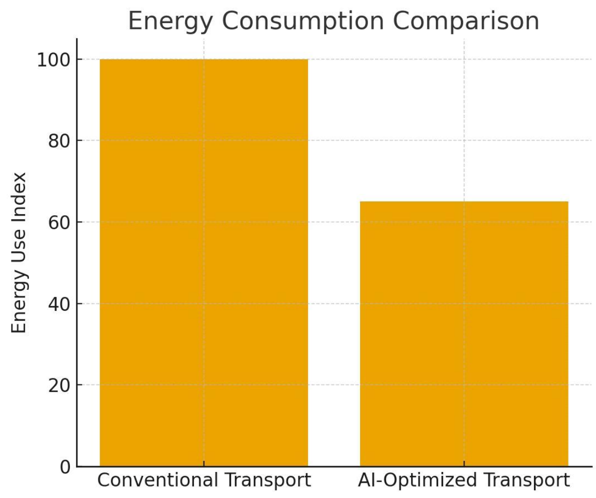

Figure 3. Comparison of energy consumption betwee conventional transport and AI-optimized transport [6]

CONCLUSION

Intelligent traffic systems, shared transportation, driverless vehicles, and electric mobility are all made possible by AI algorithms, which are changing the face of sustainable transportation. But there are still a lot of issues with governance, energy use, and privacy. A holistic approach that combines technology, regulation, and sustainability principles will be necessary for achieving long-term climate goals.

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Evaluation of a signalized intersection using PTV VISSIM

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ABSTRACT

This article presents an assessment of the current state of regulatory measures at signalized intersections, which are increasingly becoming urgent challenges in modern cities. Using the PTV VISSIM software, the study evaluates traffic performance indicators such as delays, queue lengths, and level of service, providing insights into the effectiveness of existing control strategies. The results highlight the necessity of optimizing traffic signal operations to improve mobility, reduce congestion, and enhance overall road safety.

Keywords: Controlled intersection, PTV Vissim software complex, intersection level of service (LOS), traffic flow, traffic light cycle, phases.

INTRODUCTION

According to the National Statistics Committee, as of July 1, 2025, 4,612.7 thousand motor vehicles owned by individuals were registered in Uzbekistan. The majority of them are passenger cars (93% of the total). Currently, along with the increase in the population of our republic, the number of motor vehicles is also rapidly increasing. As a result, the traffic flow at city intersections is sharply increasing, leading to an increase in the problem of traffic congestion. In recent years, the geometric shape and control system of intersections have been improved several times in order to solve this problem. Nevertheless, the need to use modern software tools for effective traffic flow management remains. For example, the intersections of Qatortol, Lutfiy-Farkhod streets and many other road intersections in Tashkent can be cited. Such changes will require additional construction costs for the city's street infrastructure, while also affecting the efficiency of the intersection [1,2,4].

METHODS

We can use the PTV Vissim software complex to calculate the efficiency indicators of these intersections using computer programs and develop practical recommendations. Through the PTV Vissim software complex, we can test alternative options for effective management of car, bus, bicycle and pedestrian traffic by simulating them and develop the best projects. In the research work, the intersection of Shota Rustaveli Street and Gavhar Street is modeled using the PTV Vissim software complex and its current state is assessed. More than 700 thousand vehicles are registered in Tashkent, and on average several hundred thousand vehicles enter and exit the city during the day. The analysis shows that during the peak hours of the day, more than 9900 thousand vehicles move at the intersection of Shota Rustaveli Street and Gavhar Street. Shota Rustaveli Avenue has 4 lanes, Gavhar Street has 3 lanes. The maximum speed limit for light vehicles on the main roads of the city is 60 km/h, and for freight and passenger buses - 50 km/h [3,5].

Figure 1 shows the intersection of Shota Rustaveli Street and Gavhar Street in Tashkent, taken from Yandex Maps.

Figure 1. View of the studied intersection from Yandex maps.

RESULTS AND DISCUSSIONS

The study began with data collection to analyze the efficiency of the intersection of Shota Rustaveli Street and Gavhar Street. This data includes the number and type of motor vehicles, cyclists and pedestrians. The geometric parameters of the streets at the intersection, road signs, traffic length, as well as the number of road traffic incidents (collision) were analyzed. Due to the lack of data on collisions at the intersection of Shota Rustaveli Street and Gavhar Street, traffic safety was not taken into account in the study. It was determined that more than 11,000 thousand vehicles pass through during peak traffic hours of the day. The composition of moving vehicles (Figure 2): the number of cars, trucks and buses was studied. As a result of the measurements, the traffic movement of motor vehicles as well as the traffic flows by direction were analyzed through analytical counting. The data collected during the peak hours of the day for one hour was loaded into the PTV Vissim program and calculations were performed [6,7].

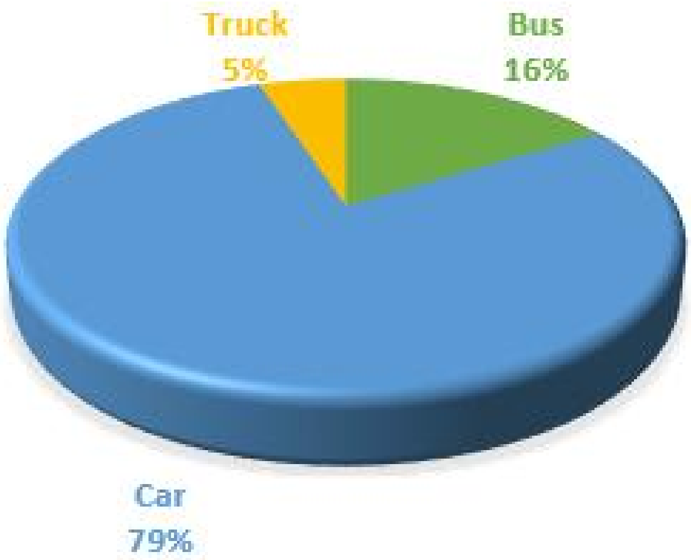

Figure 2. Share of organizing vehicles.

The number of vehicles passing through an intersection depends on the capacity of the intersection. For signalized intersections, the efficiency is determined by the average delay (delay) of the vehicles. The efficiency of signalized and unsignalized intersections is given in Table 1, which is the level of service (LOS).

LOS	Organized	Unregulated
	(second)	
A	≤ 10	≤ 10
B	> 10 – 20	> 10 – 15
C	> 20 – 35	> 15 – 25
D	> 35 – 55	> 25 – 35
E	> 55 – 80	> 35 – 50
F	> 80	> 50

Table 1. *LOS value of the intersection*

A computer model of the current state of the intersection was created using the PTV vissim program (Figure 3).

Figure 3. shows a model of the intersection of Shota Rustaveli Street and Gavhar Street.

The current state of the repaired intersection was calculated using the PTV vissim software package. The numerical results are presented in Table 3.

Table 2. Current status results of the intersection

Indicator	**Current status**
Level of Service (LOS)	D

In particular:

- the operating hours of traffic lights were changed;

- the carriageway was allocated for buses;

- in order for buses to move without stopping, public transport was given priority even during red lights, i.e., the 5.42 road sign was installed.

This solution served to increase the continuity of public transport flow, speed up passenger transportation and reduce traffic congestion. When going to work, school and other places in their personal cars, they will switch to using public transport instead of their own car.

CONCLUSION

The results of modeling and evaluation using the PTV Vissim software complex on Shota Rustaveli Street and Gavhar Street showed that the redistribution of traffic light phases, the installation of additional road signs and the allocation of a separate carriageway for buses significantly improved the traffic flow. This method serves as an effective solution for increasing the level of service of the intersection, reducing traffic congestion and giving priority to public transport. In the case of the intersection of Shota Rustaveli Street and Gavhar Street, the service level of the studied intersection was found to be at level D.

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Analysis of modern methods for calibrating parameters in microscopic modeling of transport flows

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ABSTRACT

Nowadays, many cities are facing increasing transport problems (traffic jams, environmental pollution, road accidents). To overcome these problems, transport workers and scientists are conducting a number of studies. Traffic flow modeling (for example, in the VISSIM program) is a powerful tool for analyzing, predicting and finding effective solutions to these problems. In this article, methods for calibrating input data for traffic simulation have been considered. In this process, several literature reviews on calibration were analyzed, conclusions were drawn from the results, and tasks to be carried out at the next stage were determined.

Keywords: modeling , methods, calibration , algorithms.

INTRODUCTION

Effective management of transport flows, planning of transport infrastructure, and optimization of passenger and freight services are among the most crucial tasks of today's transportation system. The increasing population, growing number of vehicles, and the increasing complexity of urban infrastructure necessitate the efficient organization of transport flows. From this perspective, interest in the field of modeling and forecasting transport flows is steadily rising.

Microscopic modeling methods enable a more in-depth analysis of the transport system. This approach considers vehicles, drivers, and road elements at an individual level. As a result, it becomes possible to obtain simulations that closely resemble real-world conditions. Software programs such as PTV Vissim, Aimsun, and Paramics are widely used for microscopic modeling of traffic flows.

However, one of the most crucial stages in the process of modeling traffic flow behavior is the correct calibration of parameters. Calibration is the process of adjusting model parameters to align with observed results in real conditions. Incorrect calibration can cause the model's results to differ significantly from those of the actual transport system.

Various calibration methods have been proposed in the literature. For instance, traditional statistical approaches are suitable for small transport networks, while optimization and artificial intelligence-based approaches yield effective results in large urban transport systems. This article analyzes modern calibration methods and comparatively examines their effectiveness.

METHODS

The methods for calibrating parameters used in microscopic modeling of traffic flows are based on various approaches. These methods can be categorized as follows:

1. Traditional statistical methods. In these approaches, the observation data collected on traffic flows are analyzed using statistical methods. For example, dispersion analysis, sensitivity analysis, and correlation analysis are widely used. While their advantages lie in simplicity and speed, their disadvantage is insufficient accuracy in complex transport systems.

2. Optimization methods. In these approaches, the process of parameter selection is carried out using optimization algorithms. The most commonly used are Genetic Algorithms (GA), Particle Set Optimization (PSO). These methods help to find the optimal solution in the multidimensional space of parameters. However, these methods require a lot of time and significant computational resources.

3. Artificial intelligence methods. Provides the possibility of efficient use of large volumes of transport data. Neural networks, Deep Learning, and Bayes approaches can deliver results with high accuracy in real-time. However, these methods require a large amount of training data and a high level of technical complexity.

Table 1.

Category	Authors	Algorithm Traffic Network	Segment	Metrics
Traditional statistical methods	Severino et al., 2021[1]	Statistical methods (GEH)	Flower roundabout	Traffic flow data
	Pan et al., 2021[2]	Statistical method (MAPE)	Intersection	Traffic flow data, capacity
Optimization methods	Park & Qi, 2005[3]	Genetic algorithm	Signalized intersection	Travel time
	Kim, 2006 [4]	Genetic algorithm	Urban arterial and freeway	Travel time and the O–D matrix
	Cunto et al., 2008 [5]	Genetic algorithm	Signalized intersections	Vehicle tracking data
	Chen et al., 2019 [6]	Experimental driving simulator data	Urban expressway	Driving behavior data, speed
	Yuan Vey, 2017 [7]	Metaheuristic algorithms	Urban freeway	Traffic flow and speed
	Fang et al., 2022 [8]	Programming code for the co-simulation framework	Motorway	Average speed, traveltime, average delay
Artificial intelligence methods	Ištoka Otkovic et al. 2013 [9]	Neural networks	Urban roundabouts	Travel time, queue parameters
	štoka Otkovic et al.2023 [10]	Neural networks	Urban roundabouts	Travel time, queue parameters, traffic flow data

The process of microscopic modeling of transport flows based on the PTV Vissim program was considered as the research methodology. In the process of parameter calibration, each approach was applied separately, and the results were evaluated comparatively.

RESULTS

The results obtained during the study were summarized as follows:

- Traditional statistical methods provide sufficient accuracy for simple transport networks in a short time. For example, with the help of correlation analysis, it is possible to quickly assess some parameters of driver behavior. However, in complex urban transport systems, the results of these methods differ significantly from real conditions.

- Optimization methods, in particular genetic algorithms and PSO, provide significantly higher accuracy. They showed effective results in multi-parameter transport models. For example, the calibration accuracy increased by 15-20% using the PSO algorithm used in the PTV Vissim program. At the same time, these methods are characterized by a large amount of calculation time.

- Artificial intelligence methods have yielded the most effective results. In the calibration process based on neural networks, the accuracy was higher than 90%. However, this required a large amount of traffic flow data. Approaches based on Deep Learning have provided real-time calibration capabilities.

Quyidagi 2-jadvalda uchta yondashuv samaradorligi qiyosiy koʻrinishda keltirilgan:

2- Table.

Calibration method	Measurement time	Benefits	Limits
Traditional statistical methods	Very fast	Simple, fast	Low accuracy in complex systems
Optimization methods	Medium	High accuracy	Too much time to calculate
Artificial intelligence methods	High	Real-time accuracy	Requires a lot of data and resources

DISCUSSION

The results indicate that there is no single universal calibration method for microscopic modeling of traffic flows. Each approach has its own advantages and limitations.

For example, in small transport networks, traditional statistical methods are sufficient to obtain quick results. However, in large transport systems, it is advisable to use optimization or artificial intelligence approaches to achieve high accuracy.

In the future, the direction of automating the calibration process will develop. With the help of IoT devices, Floating Car Data, and GPS tracking information, it will be possible to monitor traffic flows in real-time and automatically adjust model parameters.

Furthermore, the advancement of modern computing technologies (such as cloud computing and quantum computing) will serve to accelerate the calibration process in the future. Consequently, it is anticipated that combining calibration methods (for example, optimization and machine learning) will yield more effective results in the coming years.

CONCLUSION

In microscopic modeling of transport flows, the process of parameter calibration plays an important role in ensuring the accuracy and reliability of model results. Based on the research results, the following conclusions were made:

- Traditional statistical methods are suitable for ordinary transport networks and provide quick results.
- Optimization methods allow achieving high accuracy, but the calculation time is long.
- Artificial intelligence methods provide the highest accuracy, but require a large amount of data and resources.

In the future, more effective results can be achieved by combining various calibration methods in transport flow modeling. Also, the development of real-time calibration technologies plays an important role in the management of transport systems.

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Achieving Sustainable Development Goals through Implementation of the SPHERE Erasmus + CBHE Project

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ABSTRACT

Sustainable Development Goals represent a universal call to action to end poverty, protect the planet, and ensure prosperity for all. Among these, sustainable transportation plays a pivotal role in achieving climate resilience, reducing inequalities, and fostering economic growth. The SPHERE Erasmus+ KA2 CBHE project directly contributes to these goals by strengthening higher education systems in sustainable transportation (ST) across Uzbekistan and Kosovo.

Through comprehensive analysis of ST policies and practices, SPHERE identified key challenges and opportunities, providing a foundation for evidence-based reforms. The project developed six new or modernized study programs with 72 specialized courses in sustainable transportation, equipping students with skills aligned with labor market needs. Additionally, targeted training programs for professionals were designed based on stakeholder surveys and workshops, with the aim to enhance workforce competencies in green mobility solutions.

By establishing modern ST laboratories and facilitating knowledge exchange between EU and partner country universities, SPHERE created sustainable infrastructure for long-term capacity building. These concrete outcomes advance SDG 4 (Quality Education), SDG 9 (Industry and Innovation), and SDG 13 (Climate Action), while regional partnerships underpin SDG 17 (Global Collaboration). The project shows how academic innovation and working together across borders can accelerate progress toward sustainable development.

Keywords: Sustainable Development Goals (SDGs), Sustainable Transportation (ST), Higher Education Institutions (HEIs), European Green Deal, SPHERE Erasmus+ project, Curriculum Development, Capacity Building.

INTRODUCTION

There are many definitions of sustainable development, but one of the most frequently used in the literature is that sustainable development is "meeting the needs of the present without compromising the ability of future generations to meet their needs".[1]

The 2030 Agenda for Sustainable Development, adopted by the General Assembly of the United Nations in 2015[2], is perhaps the most declarative act establishing sustainable development with defined goals, even if it was not the first. The preamble of this document, states: „This agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom. We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development. All countries and all stakeholders, acting in collaborative partnership, will implement this plan". The aim of the 2030 Agenda for Sustainable Development is to achieve a more sustainable, peaceful, and prosperous world by eradicating poverty, protecting the planet, and ensuring prosperity for all people by the year 2030, through 17 integrated and indivisible goals, including core principles: intergenerational equity, three pillars (environmental, social, economic) and interconnectedness.

In 2021, the European Commission (EC) officially adopted the European Union (EU) Strategy on Adaptation to Climate Change in 2021[3], as a response to the threat of climate changes, alongside with the 2030 Agenda. The new EU Adaptation Strategy links directly to recent global agreements, such as the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Agenda as well as the EU implementation of these goals. It also connects directly to major EU initiatives like the Mission for a Climate Resilient Europe and the Union's sustainable

[1] This definition of sustainability is known as the definition from the Brundtland report, "Our Common Future" of 1987, established by the World Commission on Environment and Development available at the following link https://www.un.org/en/academic-impact/sustainability.
[2] The 2030 Agenda for Sustainable Development was adopted on September 25, 2015, during the United Nations Sustainable Development Summit. https://docs.un.org/en/A/RES/70/1.
[3] European Union (EU) Strategy on Adaptation to Climate Change available at the following link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN.

finance agenda. The European Green Deal (announced in December 2019)[4] presents the Commission's plan for a sustainable green transition. At the heart of the Green Deal, the first European Climate Law proposal establishes the framework for achieving climate neutrality by 2050. The European Green Deal's Sustainable and Smart Mobility Strategy includes a mobility system that is sustainable, smart, and resilient: a system for future generations. In addition, the Council Recommendation on learning for the green transition (2022) emphasizes the need to provide learners of all ages with opportunities to find out about the climate crisis and sustainability in both formal education and non-formal education, and to make learning for the green transition a priority in education and training policies and programs. Sustainability should become part of the entire spectrum of education and training, including curricula and professional development for educators as well as buildings, infrastructure and operations.

THE SUSTAINABLE DEVELOPMENT GOALS WITHIN THE SPHERE ERASMUS + CBHE PROJECT FRAMEWORK AND WORK PLAN

One of the main aspects of sustainable development is sustainable transportation (hereinafter referred as ST) that includes objectives such as universal access, improved safety and resilience, enhanced efficiency and reduced environmental and climate impact. ST not only provides services and infrastructure for the mobility of people and goods, but it also positively impacts the acceleration of progress on other crucial global issues, such as eradicating poverty in all its forms, reducing inequality among people, strengthening women`s positions in the society, and mitigating climate change. Therefore, ST is essential for achieving of the 2030 Agenda for Sustainable Development and various EU initiatives and strategies, including the Strategy on Adaptation to Climate Change, the Green Deal and the Paris Agreement. The EU has long identified ST as one of the priorities for the decarbonization of transport in all

[4] Available at the following link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640

member states. Moreover, the success of the European Green Deal[5], depends on the possibility of making the transport system as a whole sustainable. Investments in sustainable alternative fuels and clean technologies, as well as renewals of transport fleets by public authorities and companies, are essential to achieve the necessary transition. As part of the European Green Deal, the Sustainable and Smart Mobility Strategy outlines three main actions: making all transport modes more sustainable, enabling multimodal alternatives, and creating incentives to accelerate the green transition.

Sustainable transportation within the framework of green deal (SPHERE) Erasmus + KA2 CBHE project[6] goals are complementary to goals provided in European Green Deal (Sustainable and Smart Mobility Strategy), the 2030 Agenda for sustainable development[7] and the Paris Agreement on Climate Change. Uzbekistan and Kosovo*[8] (hereinafter referred as Partner Countries/PC) polices, as a partner countries in the SPHERE project, pursue global efforts to combat climate changes and their impact.[9]

The wider objective of the SPHERE project is to improve the quality of higher education in the field of the ST in line with EU trends, contribution, polices promotion and popularization of ST, strengthen its relevance for the labour market and society. This wider objective is fully compliant with the priorities of the Capacity Building

[5] The European Commission through green deal recently announced the goal to achieve a "net-zero" Greenhouse Gas (GHG) emissions level by 2050. Transportation accounts for about 25% of greenhouse gas emissions, with road transportation accounting for three-quarters of this share. As opposed to other energy-intensive sectors, such as electricity generation and industry, emissions from transportation activities have been growing in the past years.

[6] Sustainable transportation within the framework of green deal (SPHERE) Erasmus + KA2 CBHE project, 101128065 — SPHERE — ERASMUS-EDU-2023-CBHE, begun on March 1st, 2024, all details about the SPHERE project are available at the project webpage https://sphere.pr.ac.rs/ .

[7] Such as:
- Education: Achieving inclusive and quality education for all reaffirms the belief that education is one of the most powerful and proven vehicles for sustainable development.
- Affordable and clean energy: expanding infrastructure and upgrading technology to provide clean and more efficient energy in all countries will encourage growth and help the environment.
- Sustainable cities and communities: provide access to safe, affordable, accessible and ST systems for all, improving road safety, notably by expanding public transport.
- Climate action: improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

[8] This designation is without prejudice to positions on status and is in line with UNSCR 1244.

[9] E.G the Uzbekistan Government in October 2018 endorsed and adopted a resolution in 2030 Agenda which reinforced commitment to align SDGs to national strategies and programmes. The Government adopted 16 national SDGs, 125 related targets and 206 indicators to facilitate monitoring of their implementation. Moreover, Uzbekistan joined Paris Agreement and ratified it in 2018. Development Strategy of Uzbekistan for 2022-2026 contains goals given in Green deal. Likewise, highest government officials of Western Balkan countries (Kosovo*, Albania, Serbia, Montenegro, North-Macedonia and Bosnia and Herzegovina) endorsed the Green Agenda for Western Balkans at Sofia Summit, held on 10th of November. The European Green Deal Agenda is a template for prospective steps that the EU and each of the Western Balkan countries could pursue jointly.

projects within the Erasmus+ program (Green deal). Also, the benefits for partner countries are looking for the implementing the most appropriate scientific methods and the best practice from EU HEI partners during the SPHERE project. Further, the project will also result in the development of trainings for professionals in the field of transport based on results of survey for stakeholders, organized local workshops with stakeholders in the field of transport and recommendations of EU HEI partners. Finally, the benefits for PC HEI partners include the implementation of the most appropriate scientific methods and the best practices for the implementation of sustainable transport.

As an interregional project it brings together EU countries with two regions Central Asia and the Western Balkans. Higher education institutions, together with the non-academic and associated partners, put together their work within the SPHERE project for more than a year and a half. Specifically, the SPHERE project consortium consists of the following institutions:

➢ EU HEI partners are: University of Maribor - UM (Slovenia), Polytechnic University of Crete - TUC (Greece), Polytechnical University in Madrid - UPM (Spain) and Polytechnic University in Torino - PTT (Italy).

➢ PC HEI partners – four form Uzbekistan are: Turin Polytechnic University in Tashkent - TTPU, Toshkent Davlat Transport University - TSTrU, Tashkent Kimyo International University - KIUT, Jizzakh Branch of National University of Uzbekistan Named After Mirzo Ulugbek - JBNUU, and two from Kosovo* - University of Mitrovica – UPKM Coordinator of the project and Academy of Applied Studies Kosovo and Metohija - AASKM (hereinafter refer to as Partner countries or PC)

➢ PC non-academic partners are: Ministry of Higher Education, Science and Innovations of the Republic of Uzbekistan - MHESI (Uzbekistan), "Uzavtotranstexnika" scientific and production centre state unitary enterprise - UZTT (Uzbekistan) and W3Lab Digital Solutions L.L.C. - W3LAB (Kosovo*).

➢ The associated partner is: JV "Samarkand Automobile Factory" – SAF (Uzbekistan),

Current risks of climate change and challenges and barriers for the implementation of ST have initiated the preparation of the SPHERE project and are based on several key points:

1) Introduction of new technologies in partner countries is still in developmental phase - with very poor economic, technical and educational environment for their application. The education system is not sufficiently developed and adapted to new challenges, and is extremely incompatible in terms of supporting the achievement of the green transition goals in the field of ST. A comprehensive transition to ST still faces considerable obstacles, despite the fact that many conventional transport systems are changing. This transformation can be advanced through the education and the improvement of study programmes and through the raising public awareness of the importance of ST.

2) Between 2010 and 2019, transport CO2 emissions have increased in all regions, except Europe, where they decreased by 2%, a drop attributed to advanced fuel economy regulations and advancing initiatives on sustainable urban mobility.[10] The Central Asian and West Balkan regions, have not sufficiently adopted the concept of ST. The Central Asian region is landlocked with a dry, continental climate and is highly vulnerable to climate change, with temperatures rising by 1.6°C since 1880 and forecasted to increase further. Its total greenhouse gas emissions make up about 1% of global emissions, mainly from the energy and transport sectors.[11] Climate change is also heavily affecting the Western Balkans, forecasting temperature increases running from 1.7°C to 4.0°C[12]. Emissions from transport, tourism, and other sectors are rising,

[10]SLoCaT Partnership. (2021). *Transport and climate change global status report – 2nd edition: Tracking trends in a time of change*. https://tcc-gsr.com/wp-content/uploads/2021/06/Slocat-Global-Status-Report-2nd-edition.pdf.

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posing challenges. Strategic action in sustainable transport includes modernizing vehicles, improving traffic management, promoting eco-friendly modes, and strengthening authorities to reduce pollution.

3) Countries in special situations, namely underdeveloped countries and landlocked developing countries, face numerous challenges in the pursuit of sustainable development, with transport often being a key element of these. In the area of ST, the limited availability of human resources or weak institutions poses capacity constraints in many countries. Transport is likely to change in the future, and education, professionalization, and skills in the labor market will need to keep pace. Developing countries, such as Uzbekistan and Kosovo* lack the highly specialized expertise needed to develop ST systems and implement them effectively. Project SPHERE is the response to limitations that impact the development of ST in those two partner countries. Lack of courses/curricula in the area of sustainable transport is the common characteristic of both PC, which presents the basis for collaboration of those HEIs and justifies the preparation of the cross-regional project in order to develop curricula related to ST. Namely, students do not have the opportunity to acquire adequate competencies and skills in the field of ST. For these reasons five out of six PC HEIs will accredit completely new study programmes related to ST. Furthermore, there are no adequate laboratories and practical classes where students could be on site and become familiar with the concept of the ST. It is necessary to transfer innovative and newly developed technologies and know-how best practices from the EU to PC HEIs in the field of the ST by developing comprehensive curricula. EU HEIs have significant experience in successful education of students in the field of ST, advanced knowledge, qualified experts, modern laboratories and rich experience in the development and modernization of study programs. Experiences from EU HEIs are valuable and necessary for the introduction of up-to-date courses in PC HEIs curricula.

THE SPHERE ERASMUS+ PROJECT OBJECTIVES

Community. Belis, C., et al. (2024). Status of Environment and Climate in the Western Balkans (2nd ed.). Luxembourg: Publications Office of the European Union. Retrieved December 13, 2024, from https://publications.jrc.ec.europa.eu/repository/handle/JRC140061

Based on the identified needs for promotion and implementation of ST at the PC HEIs and taking into account specific objectives defined by the Erasmus Plus Programme Guide (section Capacity Building in the field of higher education), the specific objectives of the project for all PC partner countries were set up as follows:

1) identification and recommendation for managing of ST key issues in partner countries,

2) to improve and develop the existing curricula for undergraduate and master studies in accordance with Bologna requirements and national accreditation standards by implementing new courses in the field of ST[13], and

3) to develop and implement a training program for transportation professionals that aligns with current scientific knowledge on issues related to ST.[14]

The enhancement of knowledge, skills, and abilities, has paved the way for the successful application of ST in the Partner countries. Promotion of ST is aimed at raising the awareness of importance of environmental protection among the public and stakeholders and creating preconditions for the implementation of activities foreseen by the Green Deal and the 2030 Agenda for Sustainable Development. This project brings together different areas of study such as training and education, environmental protection, ST, and organization and exploitation in transport, which are usually considered separately but are closely related. Therefore, the implementation of knowledge from all mentioned fields can contribute to the accomplishment of standardized and interrelated ST solutions. It is planned that modernized study programs of bachelor and master studies shall be based on contemporary comprehension of road transport, including contemporary literature that describes this

[13] These courses should cover provisions concerning Ecological and sustainable design in road traffic, new technologies of means of transport, improvement of transport (integral transport systems, drivers' education, logistics and organization of transport…), types of transport that do not pollute the environment, environmental protection. The aim of the improved study programs is to include the different disciplines such as organization of transport, intelligent transport systems, environmental sciences as well as through establishment new ST laboratories at PC HEIs. The equipment obtained through the project will be used for the establishment of the laboratories where the students will have practical lectures related to the ST.

[14] The analysis of citizens' and public sector awareness will be done aiming to identify the level of knowledge about the ST, in order to prepare effective training programmes for transportation professionals. The selected teachers from PC HEIs will prepare programmes of the trainings that will be applicable in Partner countries.

field, respecting the relevant and valid national and international regulation that governs the field of ST. Therefore, study programmes will ensure the acquisition of competences that are socially justified and useful and are professionally applicable in the field of ST. Upgraded/modernized study programs of for bachelor`s and master will enable students to use modern information technologies, and to apply modern solutions, and planning and logistics related to the field of ST. In addition, the objective of the study programs will be the development of creative skills of students in considering the problems, analysis and critical thinking, as well as to train them to work in diverse conditions and dynamic environments.

CONTRIBUTIONS OF THE SPHERE PROJECT TO ACHIEVING SUSTAINABLE DEVELOPMENT GOALS

Analyzes key issues related to ST – *Work package 2*

First steep – data on national policies, regulatory frameworks, applicable standards, and SWOT analyses was collected through collaboration between experts from EU and PC partner HEIs. The results of this analysis were consolidated into the Integrated Report[15], which offers commentary on the current state and challenges in the field of sustainable transportation (ST).

In parallel, a comparative analysis of curricula was conducted to identify the best EU educational practices that could be implemented in PC countries. The workshop held at the University of Maribor facilitated the exchange of experiences and the definition of key competencies required for future transport engineering professionals. These findings were documented in the Report on the Analysis of Existing Curricula[16].

Finally, the latest technologies and methodologies were presented through reports on innovative ST practices in the EU (D2.4) and the Maribor workshop, serving as a foundation for enhancing educational programs in PC countries. This introduction sets the stage for further discussion on the development of competency catalogues and

[15] Reports on analyses key issues related to sustainable transportation as Deliverable D2.1 is available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D2.1-Reports-on-analyses-key-issues-related-to-ST.pdf
[16]Deliverable D2.3 available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D2.3-Report-on-analyses-existing-curricula-related-to-ST.pdf .

courses, which will improve the adaptability of educational systems to the demands of sustainable transportation.

The development of ST related study programs and establishment ST laboratories – *Work package 3*

Second steep – to accredit or modernize undergraduate/master study programs at each PC HEI as one of the most important SPHERE project milestones, catalogue of competences and courses has been developed. In this regard, the aims, specific competences, and learning outcomes, as well as teachers' competencies that will hold courses for undergraduate/master curriculum related to ST, were defined. During the realization of this task, non-academic and associated partners presented the most valuable competencies in accordance with the information obtained from the labor market and business sector. As result of this task, catalogues of competencies have been prepared by PC HEIs.[17]

All PC HEIs defined the courses and their designs based on the targeted competencies for undergraduate/master students. The content and syllabi for SPHERE undergraduate/master curricula were developed in alignment with planned activities, assignments, and teaching materials aimed at supporting student learning outcomes and ensuring quality standards. PC HEIs created catalogues of courses and syllabi consisting of the following components: description of the study program (title, level, structure, objectives, outcome of the study program, title of diploma, conditions for enrolment, list of the compulsory and elective courses, syllabuses on new/modernized courses, matrix of competences etc.). The design of all proposed competences and curricula was revised by EU partners. As a result, the SPHERE Catalogue of Courses was created.[18] All six PC HEIs compiled lists of undergraduate/master courses within either existing or newly study programs, as outlined below:

[17]Deliverable D3.1 and available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D3.1-Catalogue-of-competences.pdf.

[18] Deliverable D3.3 available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D3.3-Catalogue-of-courses-created.pdf

- University of Mitrovica (UPKM): Modernization of the undergraduate study program Road Traffic and Transport with 5 courses (2 new, 3 updated), totaling 30 ECTS, (modernization procedure accomplished).

- Turin Polytechnic University in Tashkent (TTPU): Accreditation of the undergraduate study program Sustainable Transport with 16 courses (15 new, 1 updated), totaling 98 ECTS, (accreditation procedure in progress).

- Academy of Applied Studies of Kosovo and Metohija (AASKM): Reaccreditation of the master study program Road Traffic and Transport with 6 courses (3 new, 3 updated), totaling 36 ECTS, (reaccreditation procedure accomplished).

- Tashkent State Transport University (TSTrU): Accreditation of the undergraduate study program Sustainable Transport with 16 courses (15 new, 1 updated), totaling 98 ECTS, (accreditation procedure accomplished).

- Tashkent Kimyo International University (KIUT): Accreditation of the undergraduate study program Sustainable Transport with 16 courses (15 new, 1 updated), totaling 98 ECTS, (accreditation procedure in progress).

- Jizzakh Branch of the National University of Uzbekistan named after Mirzo Ulugbek (JNBNU): Accreditation of the undergraduate study program Sustainable Transport with 13 courses (13 new, 0 updated), totaling 80 ECTS, (accreditation procedure accomplished).

In order to prepare preconditions for accreditation ST study programs within the SPHERE project at Uzbek HEIs very important role-played Ministry of Higher Education, Science, and Innovation of the Republic Uzbekistan. By order of the Minister, the Classifier of Higher Education Fields and Specialties was reapproved with relevant amendments and additions These programs were developed within the SPHERE project[19].

[19] Resolution of the Cabinet of Ministers of the Republic of Uzbekistan on the approval of the state educational standards of higher education #343 from August 16, 2001 available at the following link https://lex.uz/acts/-361387, This addition includes a new program, 60711900 - Barqaror transport (Sustainable transport), for the bachelor's level and 70711901 - Barqaror transport, for the master's level available at the following link: https://api-portal.gov.uz/uploads/730a9ca0-03e3-fed1-6520-8ae1cad4ab79_media_4751.pdf .

According to the Catalogue of Courses, 72 ST-related courses will be developed within the SPHERE project (63 new and 9 upgraded), bearing 440 ECTS. Moreover, four trainings for PC HEI teaching staff with the participation of 107 participants (81 PC & 26 EU staff) have been performed and reported[20]. The goal of the trainings was to educate PC teachers about the innovative teaching methods as well as to improve the professional, pedagogical, and methodological knowledge related to ST. During the trainings of teaching staff, study visits have been performed, aiming to perform the introduction of training practices for professionals in the field of transportation in EU partner countries.

Laboratories established

All PC HEIs established new/modernized ST laboratories and prepared decisions made by their university/faculty Authorities. Purchased equipment was installed in laboratories, inventory books were prepared and labeled with the EU stickers.[21]

Figure 1: Laboratory for traffic and transport UPKM.

[20] D3.4 Report on Teaching staff trained is available on the SPHERE platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D3.4-Teaching-staff-trained.pdf .

[21] D3.2 Reports on ST laboratories Established is available on the SPHERE platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D3.2-Report-on-ST-laboratories-established.pdf

Figure 2: Laboratory on sustainable Transportation AASKM.

Figure 3: Laboratory on sustainable urban mobility TTPU.

Figure 4: Laboratory on Department of traffic engineering and management KIUT.

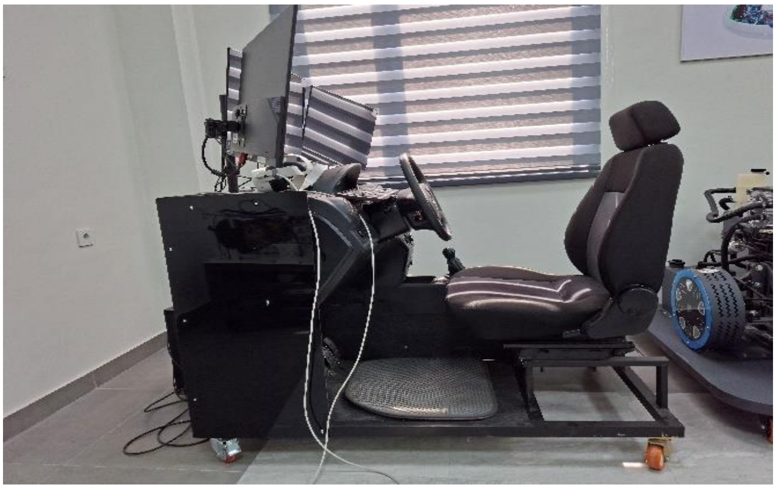

Figure 5 Laboratory for sustainable transport TSTrU.

Figure 6. Laboratory for sustainable transportation field JBNUU

Training programs for professionals in the field of transportation were developed - *Work package 4*

Third steep – a survey targeting transportation stakeholders at PC was designed to assess the current state of the sustainable transport (ST) sector. It aimed to identify gaps in knowledge, awareness, behavior, attitudes, and communication among stakeholders related to ST. The questionnaire was divided into three main sections, each designed to address a specific aspect of the study's objectives. The first section focused on collecting sociodemographic information about the participants. The second section of the questionnaire examined topics central to sustainable transport. The third section delved into the quality and reliability of the current sustainable transport system. There were 846 responses out of the 800 initially foreseen collected across the partner countries combined.

Following the collection of the survey results, two local workshops for sustainable transportation stakeholders (representatives of the private and public companies from the industry and business sector, local authorities dealing with transportation, NGOs, primary and high schools, educational institutions in general, etc.) were organized at PC HEIs, and attended by 108 participants from 26 different stakeholder institutions combined.[22] Local workshops served to present to the stakeholders results of the survey conducted. Also, during these workshops, the needs of the transportation stakeholders have been identified, as well as obstacles and weaknesses, and opportunities of the implementation of trainings for transportation professionals (SWOT analysis). Based on the results of the survey and workshops with stakeholders, a report on the survey has been compiled.[23] These reports have been the main basis for the preparation of training programs and materials at PC HEIs, together with the Report on Trainings for ST Professionals[24], where the trainings for professionals in the field of transportation and the description of their organization at EU partner HEIs have been introduced.

As the final step within Work Package 4, PC HEIs have developed training materials focused on the future-oriented sustainable transportation (ST) issues, tailored to local needs and capacities. These materials are considered key to advancing sustainable transportation management and workforce qualifications. The training content has been prepared in electronic formats (presentations, handbooks, e-books,

[22] The local workshop was held at AASKM on 24th of October 2024, with 33 participants from 11 stakeholder institutions. In Uzbekistan, the workshop took place at TRSTU on 19th of October 2024, involving 75 participants (both in-person and online) from 15 stakeholder institutions.

[23] Deliverable D4.1 and available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D4.1-Reports-on-survey-for-transportation-stakeholders.pdf.

[24] Deliverable D4.2 and available on the SPHERE project platform at the following link: https://sphere.pr.ac.rs/wp-content/uploads/SPHERE-D4.2-Reports-on-trainings-for-professionals-in-the-field-of-transportation-in-EU-HEI-pa.pdf .

etc.) as well as two bilingual handbooks[25]. All materials were developed in line with EU best practices and reviewed by EU partner institutions.

CONCLUSION

The SPHERE Erasmus+ CBHE project represents an important contribution to achieving the Sustainable Development Goals (SDGs) by enhancing education, research, and practice in the field of sustainable transportation (ST). Through collaboration between European and partner universities, the project has enabled curriculum modernization, development of new study programs and establishment of laboratories, thereby improving the quality of higher education in line with best European practices.

The analysis of sustainable transportation conditions in Uzbekistan and Kosovo* identified key challenges as well as opportunities for implementing green mobility solutions. The developed/accredited study programs (totaling 72 courses) and training programs for professionals have provided specialized skills development for the future workforce, while laboratory construction has enabled practical application of knowledge. These results directly contribute to Sustainable development goals, especially to: Quality Education, Industry, Innovation and Infrastructure and Climate Action.

By strengthening higher education capacities and promoting sustainable transport solutions, the SPHERE project has laid the foundations for long-term transformation toward greener and more inclusive mobility. Its model of collaboration between academia, the public sector and industry serves as a roadmap for future sustainable development initiatives.

AKNOWLEDGMENT: This research (paper) has been supported by Erasmus+ Capacity building in Higher Education project 101128065-SPHERE-ERASMUS-

[25] Handbook and presentations for ST trainings are freely available at the SPHERE project website at the following link: https://sphere.pr.ac.rs/dissemination/st-training-presentations/.

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LEGAL FRAMEWORKS, POLICIES AND REGULATIONS FOR SUSTAINABLE TRANSPORTATION

Implementation of paid parking systems in Tashkent city

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ABSTRACT

In 2024, the city of Tashkent launched a paid parking system under the "Poytaxt Parking" initiative, aimed at modernizing urban transport infrastructure, reducing traffic congestion, and enhancing safety [1]. This study provides an in-depth analysis of the system's economic efficiency, public acceptance, infrastructural and environmental impact. The findings, based on a mixed-method approach, reveal that although the system has increased municipal revenue, it has also encountered several challenges, including public dissatisfaction, a rise in illegal parking, and limited environmental benefits. The article offers strategic development directions and presents practical recommendations for specialists and urban policymakers.

INTRODUCTION

As the capital of Uzbekistan, Tashkent has undergone rapid urbanization over the past decade. By 2025, the city's population had exceeded 3 million, and the number of registered vehicles surpassed 1 million [1]. This has placed considerable pressure on the transport infrastructure, resulting in traffic congestion, a shortage of parking spaces, and widespread disorderly parking in central areas [4].

In 2024, the Tashkent city administration introduced a paid parking system designed to optimize the urban transport network, regulate vehicle flow, and strengthen the municipal budget [3].

The implementation of the system was inspired by international best practices. Cities such as Moscow, Budapest, and Almaty have reported a 15–25% reduction in congestion following the introduction of paid parking schemes [1]. In Tashkent, the system was launched on May 8, 2024, across six streets, and by September 2025, it had expanded to cover 86 streets with a total of 13,208 parking spaces [6].

This study aims to evaluate the system's economic, social, infrastructural, and environmental effects by answering the following key research questions:

1. What is the impact of the paid parking system on the city's transport infrastructure?
2. How effective and publicly accepted is the system from an economic standpoint?
3. What are the positive and negative consequences of the implementation?

METHODOLOGY

This research employs a mixed-method approach, combining both qualitative and quantitative methods. Data were collected from the following sources:

• **Secondary Data Analysis:** Reports and articles from Gazeta.uz [1–6], Kun.uz [7], Daryo News [8, 9], Zamin.uz [10], Central Asia Business [11], the official website of the Tashkent City Administration [12], lex.uz [13], and other public sources;

• **Statistical Data:** Information provided by the Tashkent City Administration and the Department of Transport regarding the number of parking spaces, user statistics, and revenue figures [12];

• **Surveys and Interviews:** Data were gathered from 300 local residents and 10 transportation sector experts;

• **Comparative Analysis:** The performance of the paid parking systems in Moscow and Seoul was compared to Tashkent's experience [14].

Data analysis was conducted using SPSS software through descriptive statistics and correlation analysis. Content analysis was applied to systematically interpret qualitative data obtained from secondary sources.

RESULTS

Historical Development

The introduction of the paid parking system in Tashkent can be traced back to 2022. On December 29 of that year, the mayor of Tashkent issued a decree mandating the creation of paid parking zones along 10 central streets (including Fidokor, Amir Temur, Nukus, Bratislava, Mirobod, Glinka, Avliyoota, T. Shevchenko, Said Baraka, Moshtabib, and Yakub Kolas), and delegated the operation of these spaces to the private company “Kasy Park” LLC [8]. This decision was based on a presidential resolution aimed at further improving the city’s public transport system [8]. The project was implemented as a public-private partnership (PPP), with a total investment of 9.732 billion UZS and a contract duration of 10 years [8].

In 2024, a new paid parking framework was approved by Tashkent Mayor Shavkat Umurzakov, including a citywide tariff zoning scheme [7]. The system officially launched on May 8, 2024, starting with 680 parking spaces across six streets (Amir Temur Avenue, Istiqbol, Zarafshon, Bukhara, Shahrisabz, and Mirobod), and is projected to expand to 13,208 spaces across 86 streets by September 2025 [6]. In November 2024, a public auction was held for 262,800 square meters of parking area, during which Balcomuz LLC won the bid with a 120.1 billion UZS offer—twice the starting price. This auction was organized to ensure transparency and to stimulate private sector involvement in urban infrastructure [11].

In 2025, the city’s investment firm Toshkent Invest allocated 8 billion UZS to develop specialized software for managing the paid parking system. The software contract was awarded to Streetpark Systems, whose product aims to automate system management and enhance user convenience [9]. On April 12, 2024, the Cabinet of Ministers issued Resolution No. 202/24, which established the legal foundation for the paid parking system and laid the groundwork for future regulation and expansion [13].

ECONOMIC IMPACT

The paid parking system has significantly contributed to the city's revenue stream. Between November 2024 and May 2025, the system generated more than 5 billion UZS [6]. The use of e-auctions for leasing parking zones improved transparency and boosted income by 15%—from 4.3 billion UZS at the end of 2024 to 5 billion UZS in early 2025 [2]. During a second auction held on December 17, 2024, Streetpark Systems won a contract worth 62.93 billion UZS—10% higher than the initial offer—for managing 262,800 square meters of parking space, including 6,571.3 square meters near metro stations [2].

However, the system also posed challenges for small businesses. The average monthly lease for parking spaces reached 2 million UZS, reducing the profits of small entrepreneurs by up to 20%. For instance, a café owner in the city center reported that 30% of their monthly income was being spent on parking-related expenses [5]. In terms of pricing, hourly rates varied by location—ranging from 5,000 to 12,000 UZS—which many residents considered unaffordable [1].

Tariff Zone	**Zone Boundaries**	**Hourly Rate (UZS)**
Zone 1	As defined by the Tashkent City Mayor's Resolution No. 159-14-Q/23, dated March 3, 2023	12,000
Zone 1		10,000
Zone 1		8,000
Zone 1		6,000
Zone 1		5,000

Despite the system's financial success, several experts—such as economist Otabek Bakirov—have voiced concerns about potential monopolization in the auction process. He recommended subdividing auction lots to encourage greater competition [5].

International case studies offer relevant insights. For example, in Seoul, preferential rates for small businesses have been implemented to protect commercial diversity—a practice that could be adapted in Tashkent [14]. The Tashkent City Administration took initial steps in this direction by approving a resolution on October 15, 2024, to introduce discounted tariffs for small businesses. However, as of now, full implementation has yet to be achieved [12].

SOCIAL IMPACT

Public perception of the paid parking system has been mixed. According to survey data, 62% of respondents (186 individuals) rated the system as effective in reducing traffic congestion, assigning it an average of 3.8 on a 5-point Likert scale. However, 48% (144 respondents) felt that the prices were too high [4].

Particular difficulties were noted among women (65%) and elderly citizens (72%), who cited issues with the complexity of the payment system—especially with the user interface of the "Poytaxt Parking" mobile app [4]. The app became available on App Store and Google Play starting May 10, 2025, but initial users reported a cumbersome payment process [6]. Notably, 80% of respondents aged 60 and above said they had trouble using the app [4].

On the positive side, the system has encouraged greater use of public transportation. Compared to 2024, monthly public transport ridership increased from 150,000 to 165,000 in 2025, reflecting a 10% growth [3]. This suggests that paid parking has prompted some residents to switch from private vehicles to buses and the metro. However, high parking costs continue to place an additional burden on low-income populations, potentially widening social inequality [4].

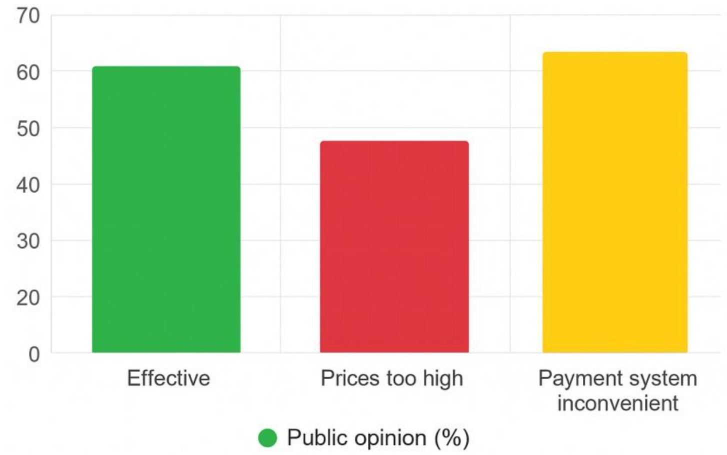

Figure 1. The Social Impact of Paid Parking

Note: This chart shows public attitudes toward the system [4].

IMPACT ON TRANSPORT INFRASTRUCTURE

By May 2025, the number of paid parking spaces increased from 3,000 to 3,600 — a 20% growth [3]. The system was initially launched on May 8, 2024, with 680 parking spots across 6 streets (Amir Temur Avenue, Istiqbol, Zarafshon, Bukhara, Shahrisabz, and Mirobod). By September 2025, it had expanded to 13,208 spaces across 86 streets [6].

Vehicle circulation in the city center decreased by 10%, dropping from 50,000 to 45,000 cars per day. As a result, the average driving speed increased from 37 km/h to 42 km/h [4]. For example, on Tuytepa Street (which has 65 parking spaces), traffic congestion decreased by 20%, and the average speed rose from 35 km/h to 40 km/h [4].

However, some negative effects have also been observed. In suburban areas, illegal parking cases increased by 30%, with monthly incidents rising from 1,000 to 1,300 [3]. This indicates that drivers are avoiding paid parking zones and switching to unregulated parking instead.

Currently, no fines are being imposed due to the absence of relevant provisions in the Administrative Liability Code. However, amendments to the law are expected in the third or fourth quarter of 2025 [6]. According to Resolution No. 202/24 of the Cabinet of Ministers of the Republic of Uzbekistan, dated April 12, 2024, proposals are being developed to introduce a penalty system for illegal parking [13].

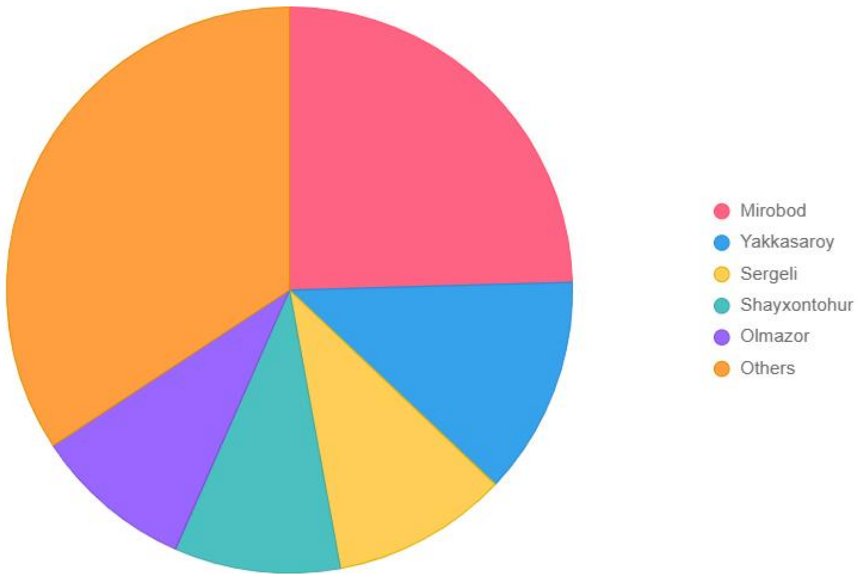

Figure 2. Distribution of Paid Parking Zones in Tashkent

Note: This map illustrates the geographic spread of paid parking areas across the city. The largest areas are located in Mirobod (71.9 thousand sq. meters), Yakkasaroy (36.5 thousand sq. meters), Sergeli (29.5 thousand sq. meters), Shaykhontohur (27.8 thousand sq. meters), Olmazor (26.7 thousand sq. meters), and other districts (100.3 thousand sq. meters) [3].

ENVIRONMENTAL IMPACT

The system has led to a 5% reduction in air pollution (CO_2 emissions), lowering the annual emission from 500 tons to 475 tons [3]. However, this result fell short of the expected 10% reduction. The shortfall is attributed to drivers avoiding paid parking zones and taking longer routes, which increased fuel consumption and reduced the environmental benefits [3].

Although no incentives for electric vehicles (EVs) have been introduced yet, such measures are seen as a critical step toward enhancing environmental impact in the future [6]. Proposals include allocating dedicated EV parking spaces and offering discounted rates. According to a report from Zamin.uz, by the end of 2025, 500 dedicated EV parking spots are expected to be introduced in Tashkent [10].

DISCUSSION

Economic Aspects

The paid parking system has generated significant revenue for the city budget, especially through the e-auction mechanism, which has improved transparency [2]. However, high lease prices have created challenges for small businesses and may worsen economic inequality [5].

Economist Otabek Bakirov has warned of monopoly risks within the auction process and suggested splitting up lots to increase competition [5]. International practice, such as in Seoul, shows that discounted rates for small businesses can help address this issue — a strategy that could be replicated in Tashkent [14]. According to the Tashkent City Government's resolution from October 15, 2024, preliminary steps toward introducing preferential tariffs for small businesses are being taken, though they have not yet been fully implemented [12].

Social Aspects

The social impact of the system is mixed. On one hand, increased use of public transport has been recorded as a positive outcome [3]. On the other hand, high pricing and a complex payment system have created difficulties for certain social groups — particularly women and the elderly [4].

Simplifying the user interface of the mobile app and expanding payment options (e.g., adding more cash payment points) could help alleviate these issues. As Daryo News reports, there are plans to increase the number of cash payment terminals in the second quarter of 2025 [9].

Infrastructure Aspects

The system has been effective in reducing traffic congestion in the city center. However, the issue of illegal parking remains unresolved [3]. Although fines are not currently being enforced, legal amendments are expected by the end of 2025 [6].

Drawing on Seoul's experience, strict penalties and surveillance cameras have proven effective in reducing illegal parking [14]. A similar approach could be implemented in Tashkent. According to Central Asia Business, the number of monitoring cameras is planned to reach 500 by the end of 2025 [11].

Environmental Aspects

As noted earlier, the environmental impact has been lower than anticipated, largely due to longer driving routes taken by those avoiding paid parking [3]. Offering benefits to EVs – such as free or discounted parking spaces – could further reduce CO_2 emissions [6]. International examples, like Moscow, show that such incentives can enhance environmental sustainability [14]. According to Zamin.uz, Tashkent plans to allocate 500 special parking spaces for electric vehicles by the end of 2025 [10].

Recommendations

1. **Revise Pricing Policy**

Reduce hourly rates from 5,000–12,000 UZS to 4,000–10,000 UZS to attract a larger segment of the population to the system.

2. **Strengthen the Penalty System**

Increase fines for illegal parking from 100,000 UZS to 150,000 UZS and expand the number of monitoring cameras.

3. **Integrate with Public Transport**

Offer discounts on public transport with parking payments — for example, a 50% parking discount when purchasing a metro ticket.

4. **Incentivize Electric Vehicles**

Allocate dedicated parking spaces for electric vehicles and reduce their parking fees by 50%.

5. **Simplify the Mobile App**

Improve the user interface and expand payment options, such as Paynet and cash terminals.

6. **Support for Small Businesses**

Lower lease rates by 20% and introduce special discounted tariffs for small business owners.

7. Public Awareness Campaigns

Launch mass media campaigns to inform residents about the benefits of the paid parking system.

CONCLUSION

The paid parking system in Tashkent has played a key role in modernizing the city's transport infrastructure, reducing congestion, and increasing municipal revenue. Launched on May 8, 2024, on six streets, the system expanded to 13,208 parking spaces by September 2025 [6].

Economically, the system generated over 5 billion UZS in revenue for the city, although small business owners have expressed concerns over high leasing costs [2]. Socially, the initiative has encouraged greater use of public transportation, but high prices and a complex payment system have caused inconvenience for certain groups [4].

From an infrastructure perspective, traffic in the city center has decreased, yet illegal parking has become more common [3]. Environmentally, the impact was below expectations; however, introducing incentives for electric vehicles could significantly improve these outcomes [6].

Moving forward, adjusting pricing strategies, strengthening integration with public transportation, and implementing legal measures could enhance the system's overall efficiency and public acceptance.

ACKNOWLEDGEMENT

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The importance of audit in ensuring road traffic safety

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ABSTRACT

The present article conducts an analysis of the significance of road safety audits in ensuring road safety. The rapid development of the automotive industry on an annual basis poses novel challenges for road infrastructure. The analysis of international experience for the effective implementation of road safety audit practice in Uzbekistan highlighted the importance of the role of road audit in the road sector.

Key words: ensuring safety, monitoring, audit, control, integration, road traffic accident, accident scene.

INTRODUCTION

The accelerated advancement witnessed within the automotive industry on an annual basis constitutes a pivotal element in the escalating demands imposed on the extant road and street network. This phenomenon is concomitant with the exacerbation of challenges pertaining to the assurance of road safety and the augmentation of the intricacies inherent in their resolution.

The primary objective of ensuring road safety is to establish conducive and secure conditions for all road users, thereby preventing road accidents and minimizing the number of losses and damages incurred as much as possible, and maximizing the effectiveness of safe movement [1].

In the contemporary era, it is widely acknowledged that the primary objective in ensuring global road safety is to prevent road traffic accidents and to reduce the number of fatalities and injuries that result from such accidents.

According to the latest data from the International Health Organization, the number of civilians worldwide who die as a result of road accidents exceeds 3 million people per year, and the number of people who are injured exceeds 50 million people. This figure is approximately 2-3 times higher than the losses incurred during the world wars [4].

As demonstrated above, enhancing the efficacy of ensuring road safety has become a paramount concern in the contemporary era. Consequently, it is imperative to maintain unwavering attention to this matter.

It is important to note that the growing importance of motor vehicles in the unified transport system is accompanied by negative changes in ensuring road safety. When considering the substantial disparities in the development of the road network and the prevalence of motorization, it becomes evident that in this challenging circumstance, the prevention of accidents and the assurance of road safety emerges as a pressing socio-economic concern in our republic.

At present, the issue of road and street traffic safety in our country is extremely serious, as it has been at a critical level for a considerable period. The efforts of the relevant organisations charged with the responsibility of ensuring and monitoring road safety are ongoing, with every effort being made to find a way out of this situation. However, thus far, these efforts have not yet been sufficiently successful.

A primary solution to these issues in the present context is the implementation of an audit of road and street traffic safety.

METHODS

A road safety audit constitutes an official control method that is carried out by a group of independent experts at various stages of the technological readiness of roads – the products of the road sector – with a view to identifying and eliminating possible causes of accidents during the operation of roads by road users as early as possible [5].

It is evident from nearly fifty years of international experience in using security audits that effective security management programmes should be adopted based on a balance between reactive and proactive strategies, taking into account local conditions.

The efficacy of a security audit is contingent upon adherence to three fundamental criteria:

1. Availability of an audit policy.

2. It is imperative that audits are conducted at regular intervals throughout the technological development stage of each road project. This necessitates the collaborative efforts of specialists with a proven track record in the domains of road safety assurance, design, and operation.

3. The necessity of a formal audit procedure is paramount. The fulfilment of this requirement is facilitated by the provision of manuals and standard control sheets, which delineate the list of elements to be verified by auditors and the specifics of their use.

The efficacy of road safety audits has been demonstrated in a variety of contexts, including road projects of varying scales and at different stages of implementation [6].

A top-down approach is generally advocated for the execution of an audit. To illustrate this point, the road administration may undertake the following actions:

1. The implementation of one or more pilot projects on auditing is to be undertaken.

2. The development of audit policy and its subsequent adoption.

3. The necessity of continuous monitoring, improvement, development and promotion of audit methodology is paramount.

RESULTS

As previously stated, the road audit methodology has been employed in European Union countries since the 1980s (initially in Great Britain, followed by Denmark, the Netherlands, Sweden, Norway, Finland, Canada, Australia, New Zealand, and so forth).

Presently, road audits in EU countries are conducted in accordance with the provisions of the European Parliament Directive 2008/96/EC and the Rules of the Council of 19 November 2008, in addition to the European Agreement on International Highways, following the adoption of the relevant amendment in 2010.

According to the provisions set out in the Directive, a road audit constitutes an independent, detailed, and systematic technical evaluation of road safety, pertaining to the design characteristics of road infrastructure projects and encompassing all phases of its life cycle, from the preliminary design stage to the initial phase of utilisation.

In order for road safety audits to become an integral part of the life cycle of roads and an effective tool in the hands of relevant specialists in ensuring road safety, the government of the Republic must, first and foremost, ensure the introduction of amendments to the legislation of the Republic of Uzbekistan, providing for the following:

- The conduction of autonomous and unbiased road safety audits at highways and street network facilities is imperative.

The following measures are to be taken in order to conduct the audit:

- The following section will outline the general requirements for road safety audits, including the scope of their application.

- The determination of the legal status of organizations conducting audits is of paramount importance.

- The following points outline the requirements for auditors, the rules for their training and certification.

- The development of an audit methodology is required for each stage of the road life cycle.

- The initial audits are to be conducted by various organizations, with a comparative analysis of the results subsequently being undertaken.

The economic advantages of conducting a security audit:

The practice of road safety audit has been demonstrated to yield economic benefits that exceed the costs of its implementation. To illustrate this point, consider the following example:

A study was conducted in Great Britain to ascertain the advantages of auditing. This was achieved by conducting a comparison of 19 road projects with audits and 19 projects without audits to the technological chain. The constructed roads were subjected to close observation during their operational phase for a considerable duration.

The results of the audit, conducted as part of the technological process, revealed a significant reduction in the number of accidents on roads constructed using this method, with the number being five times lower than that of roads built using the traditional method.

- The following section will provide a detailed analysis of American quantitative data. The number of accidents decreased from 20% to 40% following the implementation of supplementary improvements in areas designated as 300 road accident hotspots on the New York State road network. These improvements were guided by the recommendations of an audit, which emphasised the utilisation of cost-effective measures.

- The advantages of auditing are contingent on the size and complexity of the project.

- In the United Kingdom, the financial remuneration for the attraction of audit specialists is set at 900 pounds sterling for projects with an average cost of up to 100,000 pounds sterling, and 1,500 pounds sterling for large projects. It is evident that a safety audit can yield substantial economic benefits, as evidenced by the potential for eliminating a single traumatic traffic accident. Such an incident has been shown to result in an economic loss of an average of £22,260 to the company.

- In the United States, the financial outlay required for the execution of an audit is, on average, set at a range of between $2,000 and $5,000 for each individual project, with the precise amount depending on the particular characteristics of the project in question. This data corresponds to data from Great Britain and Australia [5].

A range of design solutions can be proposed to reduce the risk of road accidents, and these solutions also incur different costs. The justification for the costs of implementing the measures recommended by the audit must be substantiated by the ratio of the benefits of reducing the risk of road traffic accidents to the costs of implementing these measures. In the event that the ratio exceeds 1.0, i.e. profit exceeds expenses, such expenditure of budget funds is justified.

The following list comprises the benefits derived by the company from the security audit:

- The objective is to reduce the risk of a road traffic accident, including the probability of such an accident occurring and the severity of any resulting incidents.

- The objective of this study is to examine the reduction of costs for measures to improve road safety during road operation.

- The provision of advanced training for employees of the road administration.

- It is imperative to enhance the cognisance of the responsibility borne by those entrusted with the domains of road planning, design, construction, and maintenance. This, in turn, will precipitate an improvement in the calibre of the decisions that are made.

- In contradistinction to the conventional approach of emphasising adherence to norms, standards, and regulations, this novel strategy places emphasis on “human” (comprising all categories of road users) as the primary factor responsible for the majority of road traffic accidents.

ANALYSIS

States that implement road safety audits regard them as a core instrument in the pursuit of objectives and the resolution of issues within the ambit of road safety management programmes.

For instance, the US National Highway Administration asserts that road safety audits should be regarded as a proactive (i.e. preventive) and cost-effective approach to enhancing road safety, as opposed to a reactive method (i.e. the reduction of accidents at the sites of existing road accidents).

The notion of a road safety audit was first introduced in Great Britain in the 1980s.

- The development of methodologies for the study of the aetiology of road traffic accidents, and the implementation of strategies for their prevention, is of paramount importance.

- It is imperative that consistent legislative changes are implemented, thereby empowering road administrations to implement the requisite measures that will serve to reduce the likelihood of a road accident.

Presently, the practice of road safety audit is widespread in Australia, New Zealand, Canada, the USA, South Africa, Denmark, the Netherlands, Singapore, the Russian Federation, and other countries.

Regardless of the stage at which the technological development of the road project is at, safety audits require the resolution of the following tasks:

- The objective is to minimise the probability of a road traffic accident at the stage of road operation.

- The utilisation of efficacious solutions is imperative to mitigate the repercussions of potential road traffic accidents on thoroughfares where the elimination of risk is unfeasible (for instance, in the context of mountainous routes).

- The reduction of costs at subsequent stages of the technological development of the road project can be achieved by identifying and eliminating defects at previous stages [5].

The integration of audit as an integral part of a modern security management system under the jurisdiction of the road administration necessitates the presence of the following important elements:

- The following section outlines the responsibilities of management.

- The existence of politics is an irrefutable fact.

- The necessity for project managers to be cognisant of the issue at hand is paramount.

- The following section will address the issue of curricula.

- The company prides itself on its team of highly experienced auditors.

It is recommended that the Administration utilise the experience gained in the pilot project to develop an official audit policy. The primary components of the official audit policy encompass the following:

- The following criteria have been established for the selection of projects, in addition to extant approaches for conducting an audit.

- The following procedure should be observed when conducting and documenting the audit, and preparing reports.

- The audit training programme is to be of particular significance in this regard. It is imperative that a key group of employees, who require the necessary knowledge to manage and conduct audits, are involved in the programme.

- The following actions are to be noted:

- Monitoring of the audit process

The implementation of the audit is not complete upon the adoption of an official audit policy. It is imperative that periodic inspections are conducted in order to ensure compliance with the established policies and the success of the audit. These inspections serve not only to verify compliance but also to demonstrate the commitment and dedication of management personnel to the continuous improvement process.

The incorporation of road safety into the ideological process by the initiators serves a dual purpose. Firstly, it ensures the protection of their assets and employees. Secondly, it contributes to the achievement of the significant goal of reducing road accidents [7].

It is evident that audit plays a pivotal role in ensuring road safety. It achieves this by helping to identify and eliminate the risks associated with road accidents.

In the domain of road safety, the adage "prevention is better than cure" holds particular pertinence. The early adoption of safety measures has been demonstrated to serve a dual purpose; firstly, it protects against potential accidents, and secondly, it instils a culture of safety within society. This proactive approach constitutes a strategic investment that has the potential to yield substantial benefits, including compliance with regulatory requirements, enhanced public perception, elevated employee morale, and the avoidance of financial losses due to accidents [7].

DISCUSSION

It is imperative to acknowledge that a road safety audit constitutes a formal control method that is executed by a group of autonomous and impartial experts. The primary objective of this method is to identify and eliminate potential causes of road traffic accidents at various stages of the technological preparation of roads.

It is important to note that audit is based on different methods and techniques of analysis than those used in regulatory bodies. However, it does not replace them; rather, it complements them. A safety audit is defined as an analysis of the potential causes of accidents from the perspective of road users and participants, with the identification of potentially hazardous areas and the establishment of normative indicators of road parameters [2].

Conducting a road safety audit is imperative to enhance road safety and mitigate risks.

Legislative acts, which play a pivotal role in the regulation and assurance of road safety, and in conducting road safety audits, are the primary factor.

CONCLUSION

In light of the aforementioned points, it can be concluded that a road safety audit constitutes a necessary measure for the prevention of accidents and the enhancement of road infrastructure. This will not only contribute to the saving of lives, but also the optimisation of business expenses, the enhancement of reputation, and the compliance with legal norms.

By conducting road safety audits, companies and government organisations contribute to the creation of safe and comfortable conditions for all road users [3].

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Justification of technical specifications for car parking

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Annotation: This article scientifically analyzes the technical specifications and planning criteria based on regulatory-normative documents necessary for creating an efficient car parking system in urban conditions. The location, capacity, dimensions, safety, and parameters related to ensuring circulatory traffic of parking areas are highlighted through examples.

Keywords: car parking, regulatory documents, technical specifications, vehicle flow.

In today's world, the development of urbanization and the increasing number of vehicles have made the issue of proper and orderly car parking one of the pressing challenges for urban infrastructure. Traffic congestion in city centers, insufficient parking spaces, and safety regulations remain significant problems.

The dimensions of parking spaces are determined by national or local laws. It is essential for each country to adopt laws tailored to the types and brands of vehicles (i.e., their various sizes and maneuverability). In the absence of national regulations, designers may apply the laws of other countries, which can lead to negative consequences due to the use of incorrectly sized parking spaces.

In the pre-independence period, Uzbekistan operated based on legal and regulatory documents developed during the USSR era. After gaining independence, Uzbekistan developed its own legislative framework and regulatory documents conforming to international standards.

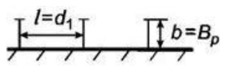
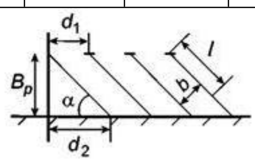
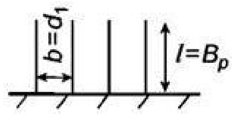
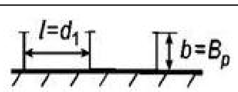
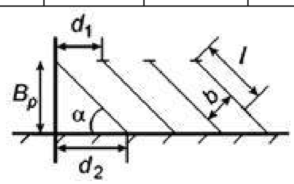
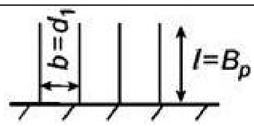
Table 1. includes the countries that have adopted State Standard (GOST) 33062-2014 "Public automobile roads. Requirements for placement of roads and roadside service facilities" [1].

Table 1. GOST 33062-2014 "Public Highways. International Standard"

Country name IC (ISO 3166) 004-97	Country code IC (ISO 3166) 004-97	Abbreviated Name of the Standardization Body
Uzbekistan	UZ	Uzstandart

According to Annex 8 of Order No. 01/2-86 issued by the Minister of Construction and Housing and Communal Services of the Republic of Uzbekistan on December 27, 2024, approving the urban planning norms and regulations SHNQ 2.07.06-24 “Urban Street Roads. Traffic Safety, Part 3”, the following Table 2 presents the methods for short-term parking of passenger cars on the edge of the carriageway [2].

Table 2. Methods of positioning passenger cars in short-term parking spaces along the edge of the carriageway

Parking space layout options	Car parking angle, α					
	0º	30º	45º	60º	75º	90º
						
Length of parking space (l), m	Not less than 6,5	5, 0	5, 0	5, 0	5, 0	5, 0
Width of parking area (b), m	2,5	2, 5	2, 5	2, 5	2, 5	2, 5
Parking space area, m²	16, 25	23, 3	18, 8	16, 1	14, 2	12, 5
Methods of arranging cars in parking spaces	Car parking angle, α					
	0º	30º	45º	60º	75º	90º
						
Line width for parking areas B_p, m	2, 5	4,7	5,3	5,6	5,5	5,0
Characteristics when defining and in parking layout: d_1 –Distance between two boundary lines of the parking space, m	6.5 (not less than 6.5)	5,0 8,08	3,54 5,3	2,89 3,22	2,59 1,47	2,5 0

d_2 –Projected length of the module's longitudinal line						
Minimum width of the car maneuvering path	3,0	4,0	4,5	5,0	5,6	6,5
Total width of the parking space	5,5	8,7	9,8	10,6	11,1	11,5

Parking on sidewalks is permitted on low-traffic streets in residential areas. In such cases, the cross slope of the sidewalk is increased, and the curb height is reduced to 5–10 cm. The clear width of the sidewalk must be at least 1.5 m and sufficient to accommodate two lanes of pedestrian movement (Figure 1). [3]

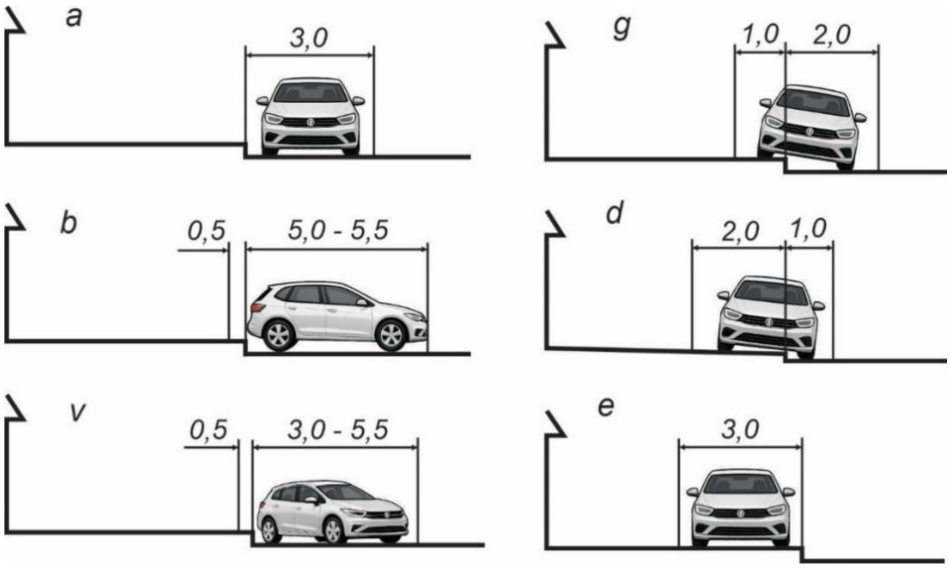


Figure 1. Different methods of parking cars on street edges:
a) Parking a car parallel to the sidewalk; b) Perpendicular parking;
v) Angled parking; g) Parking with one side of the vehicle positioned on the sidewalk; d) Parking with one side of the vehicle positioned below the sidewalk level; e) Parking on the sidewalk.

One of the biggest challenges for drivers today is entering and exiting parking spaces.

A vehicle must be positioned in a parking spot in such a way that it is quick and convenient without causing damage to other vehicles, meaning it should be maneuvered backward into place.

Parking along the edge of the roadway is carried out in three ways [4]:

-	Parallel to the roadway;
-	Perpendicular to the roadway;
-	At an angle to the roadway.

Perpendicular parking is typically used when placing a vehicle in a garage. Parallel parking along the roadway is recommended when the space between vehicles on the sidewalk is narrow but sufficient, allowing the vehicle to be maneuvered backward into the gap [4].

To perform parallel parking, cones are placed, and the vehicle is positioned accordingly, as shown in Figure 2.

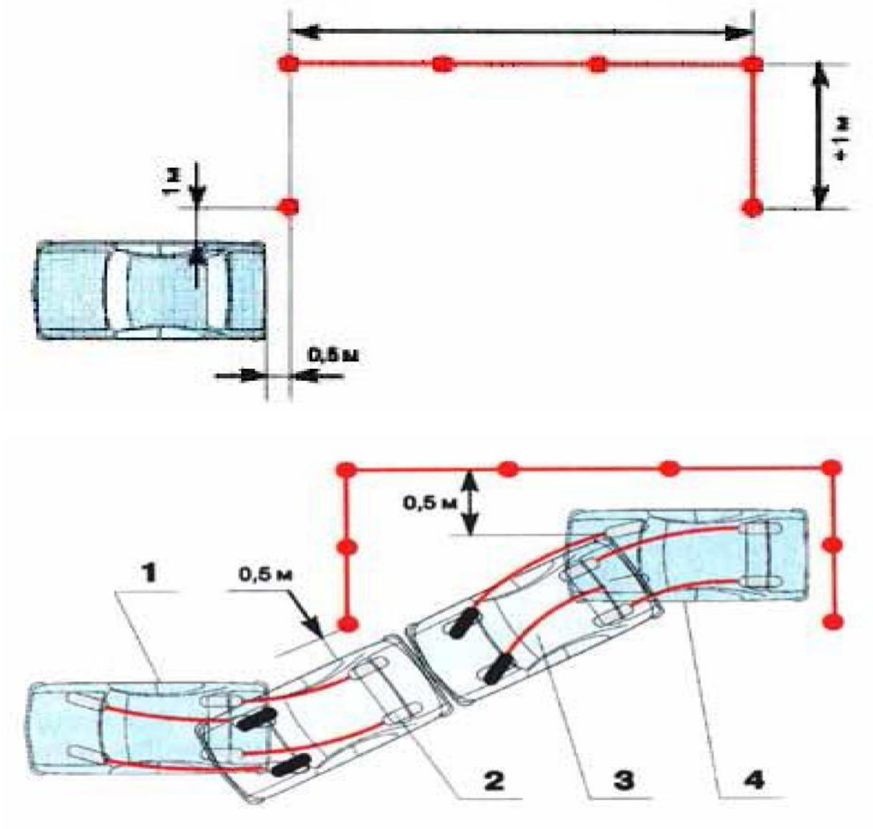


Figure 2. Method for entering a parallel parking space

In the first position, the vehicle's steering wheel must be turned to the right. In the second position, the distance between the vehicle's side and the nearest cone should be at least 0,5 meters, and from the second to the third position, the vehicle must move straight. In the third position, the steering wheel must be turned to the left, and the distance from the vehicle's rear right corner to the cones should be 0,5 meters.

During the movement from the third to the fourth position, it is crucial to monitor the vehicle's right wing. The fourth position demonstrates the result achieved after completing the exercises [4].

The use of specialized software systems to simulate this sequence of actions is becoming an integral part of modern design solutions. Advanced software systems are the optimal solution for designing road elements to determine the dynamic dimensions of vehicles.

The AutoTURN software tool can be used for simulating vehicle movements, designing road elements, and planning parking spaces. It is utilized to simulate vehicles of various sizes and their primary functional characteristics.

The following functions can be performed in AutoTURN [5]:

- Modeling vehicle movement and maneuvering at speeds ranging from 1 to 60 km/h;
- Three-dimensional movement in 3D space;
- Localizing calculated vehicle parameters to match specific vehicles;
- Graphically displaying dynamic dimensions, including trajectories of outer wheels, inner wheels, overhangs, and front wheels;
- Generating angular trajectories;
- Creating templates.

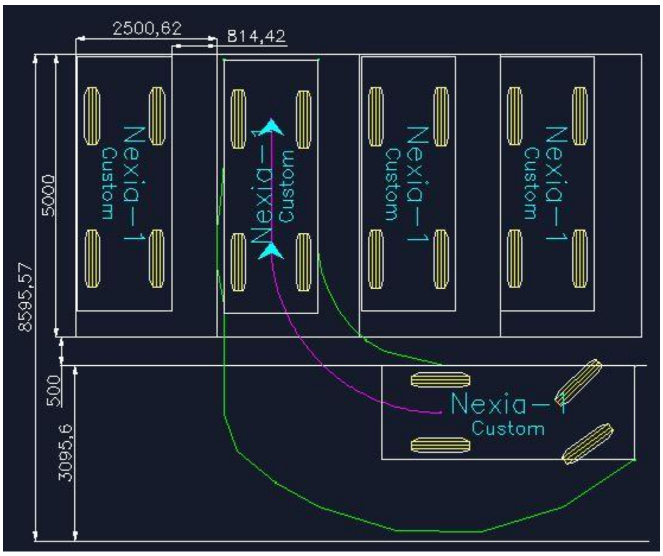
Research has been conducted using AutoTURN to recommend parking space dimensions based on the specified calculated vehicle parameters. The recommended vehicle parameters and minimum turning radii were input into AutoTURN to create its model. Experimental tests were conducted in AutoTURN to place the recommended vehicle in a parking space at angles of 90°, 60°, and 45°.

Simulations were conducted using the AutoTURN software to enable the recommended vehicle to enter and exit parking spaces positioned at various angles without difficulty. Based on the results of the experimental tests, the dimensions of the parking area were developed for recommendation, as shown in Table 3.

Table 3. Dimensions and Average Areas of a Single Parking Space

Vehicle Installation Angle (Degree)	Sizes of Elements (m)									Average area for 1 vehicle, (m²)	
	a	*b*	*c*	*d*	*e*	*f*	g	*h*	i	without maneuvering	with maneuvering
1	2	3	4	5	6	7	8	9	10	11	12
One-way passenger car parking											
90	5,0	4.1	14,1	8.6	0,5	3.1	2,5	2,5	0,5	12,5	31,8
60	5.2	3.4	13.8	8.1	0,5	2.4	2,5	2,9	0,5	15.1	30.2
45	4.7	2.9	12.3	7.1	0,5	1.9	2,5	3,5	0,5	16.7	28.1
Two-way passenger car parking											
90	5.0	4.1	14.1	8.6	0,5	3,1	2,5	2,5	0,5	12,5	25,3
60	5.2	3.4	13.8	8.1	0,5	2.4	2,5	2,9	0,5	15.1	25.1
45	4.7	2.9	12.3	7.1	0,5	1.9	2,5	3,5	0,5	16.7	25.6
Parallel passenger car parking											
180	5.5	3.0	-	5.0	0.5	2.5	2	-	0.5	11	26.4

Using the AutoTURN software, vehicles can be simulated to enter or exit parking spaces. Figure 3 illustrates the method and dimensions for maneuvering a vehicle into a parking space at a 90° angle and in a parallel position using the software.



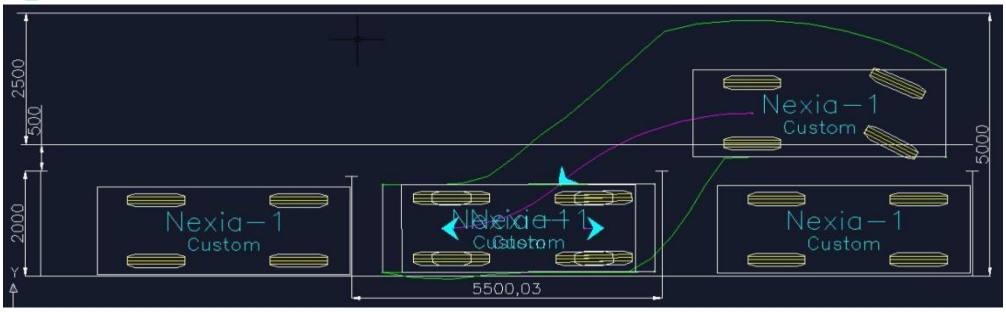


Figure 3. Method for entering a parking space at a 90° angle and in parallel position

Figure 4. below presents the recommended car parameters (length, width, minimum turning radius) in the AutoTURN software, along with the radius dimensions for positioning at the specified angle.

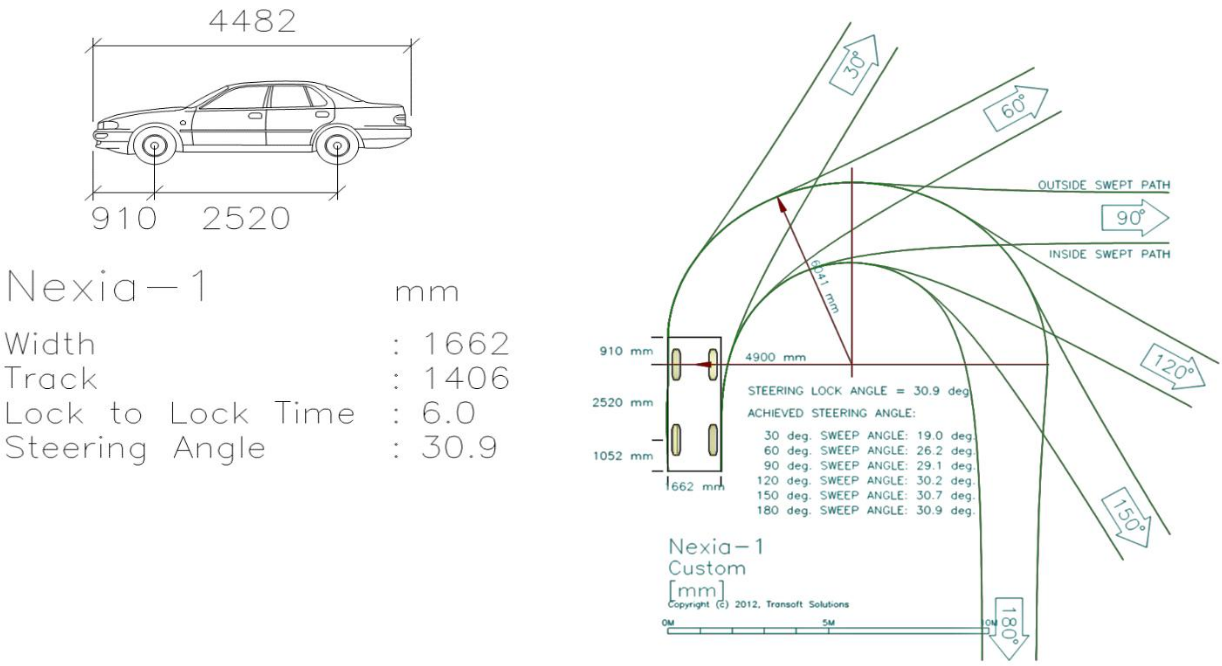


Figure 4. Recommended car parameters and turning radius

Conclusion. The vehicle parking system in urban environments should be developed not only based on technical indicators but also on safety, ergonomics, digital technologies, environmental factors, and urban integration. Through modern approaches, such as the widespread implementation of smart parking systems, it is possible to regulate traffic flow, reduce congestion, and ensure a comfortable living environment. In Uzbekistan's cities, efficiency can be achieved by scientifically justifying these indicators. Based on the research conducted, parking space dimensions for passenger vehicles and the study of vehicle maneuvering using the AutoTURN software were recommended. The results of the research can lead to economic efficiency.

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Recommendation of design vehicle parameters for vehicle parking in urban conditions

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ABSTRACT

This article analyzes the statistical regulatory documents related to the parameters of a design vehicle (length, width, minimum turning radius) for parking in urban areas. Observational research was conducted at the intersection of Sh. Rashidov and A. Navoiy streets in Jizzakh city to recommend design vehicle parameters for parking in urban conditions, focusing on the models of passenger cars. Additionally, statistical data on passenger car and truck models were utilized. Based on the research results, design vehicle parameters were recommended.

Keywords: design vehicle, frequency, cumulative frequency, parking.

INTRODUCTION

Due to the increasing dynamic characteristics of vehicles, the demand for designing and constructing roads is improving. This necessitates the introduction of the concept of a "design vehicle" in road design.

A design vehicle is defined as the dimensions and operational characteristics of vehicles used for designing roadways [1].

To determine the geometric dimensions of a design vehicle, the dimensions of various vehicles and the trends in their changes are analyzed. For the analysis of vehicle dimensions, the author examines the trends in changes of the geometric dimensions of design vehicles.

When considering the analysis of the geometric dimensions of local vehicles, it is observed that their dimensions are gradually increasing. In particular, the regulatory documents of the Republic of Uzbekistan, specifically the 25-05 MSHN "Guidelines for ensuring traffic safety on highways" do not provide a definition for the term “design vehicle”. However, this regulatory document divides design vehicles into two categories: passenger cars and trucks. For passenger cars the “Nexia” model is adopted, while for truck the “ZIL-130” is used. Table 1 presents the design car parameters of the “Nexia” and “ZIL-130” vehicle models [2].

Table 1. Design vehicle parameters in the Republic of Uzbekistan

Design vehicle	Length, mm	Width, mm	Minimum turning radius, m
Passenger car	4478	1662	4,9
Truck	6675	2500	8,9

In MSHN 05-2005-“Rules for assessing and diagnosing the condition of highways” coefficients are provided for different types of vehicles in the vehicle classification [2]. (Table 2)

Table 2. Vehicle characterisitics

Type of vehicle	ZIL-130	Nexia
Passenger car	0,28	1,00
Easy truck	0,80	2,85
Medium truck	1,00	3,57
Heavy truck	1,33	4,75
Road train	1,45	5,17
Buses with a capacity of 50-60 people	1,17	4,17
Buses with a capacity of 80-100 people	1,33	4,75

In studying the dimensions of design vehicles, the authors note that previously adopted regulatory documents recommended the dimensions of vehicles available in the 20th century. The current internal regulatory documents for vehicle models are outdated and contain information that contradicts the objectives of ensuring road traffic safety. [5,7]

Statistical data on vehicle models in operation in our Republic were used to recommend design vehicle parameters for designing parking spaces in urban conditions.

According to statistical data, passenger cars of the “Nexia 1 and Nexia 2” models, owned by individuals, are the most prevalent. As of 2018 and 2019 these models accounted for 22 % of the total, with the remaining percentage comprised of other vehicle models. Among truck the “GAZ” model accounted for 21 % in 2018, and this figure remained unchanged in 2019. The “KAMAZ” truck model recorded a high share of 19 %. [3,4,6]

Based on 2019 statistical data, the number and types of passenger cars owned by individuals (private vehicle owners) in the Republic of Uzbekistan were studied. The obtained data were processed using mathematical statistics methods, after which the modal frequency and cumulative frequency distribution were determined. All types of passenger cars were grouped by length according to the following tables:

Table 3. Grouping passenger cars according to length

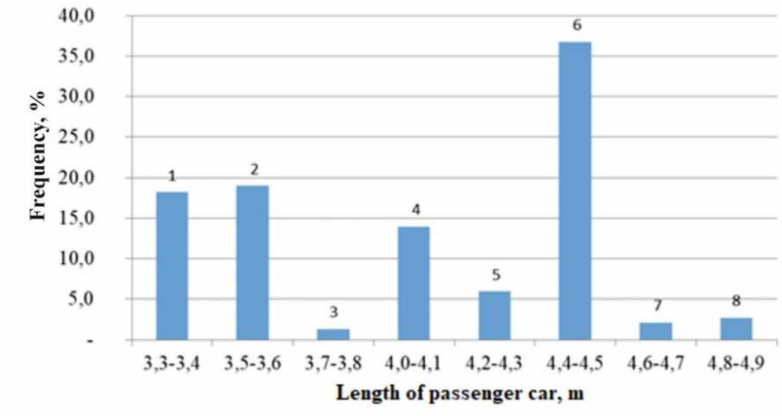
Group	Car models in the group	Length, m
1	Tiko, Damas	3,3-3,4
2	Matiz, Spark	3,5-3,6
3	VAZ-2121, Zaporojets	3,7-3,8
4	VAZ-2108, 2109, UAZ-469, VAZ-2101, VAZ 2107	4,0-4,1
5	Moskvich, VAZ-2110, Takuma	4,2-4,3
6	Nexia, Kobalt, Lasetti	4,4-4,5
7	Kaptiva, Orlando, GAZ-24	4,6-4,7
8	Epika, Malibu, GAZ-31	4,8-4,9

Table 4. Results of the study on the length of passenger cars

Length of passenger car, m	Number	Frequency, %	Cumulative frequency, %
3,3-3,4	413 253	18,2	18,2
3,5-3,6	431 246	19,0	37,2
3,7-3,8	29 952	1,3	38,5
4,0-4,1	317 294	14,0	52,4
4,2-4,3	134 869	5,9	58,4

4,4-4,5	835 662	36,8	95,2
4,6-4,7	47 728	2,1	97,3
4,8-4,9	62 181	2,7	100,0
Total	**2 272 185**	**100**	

a)



b)

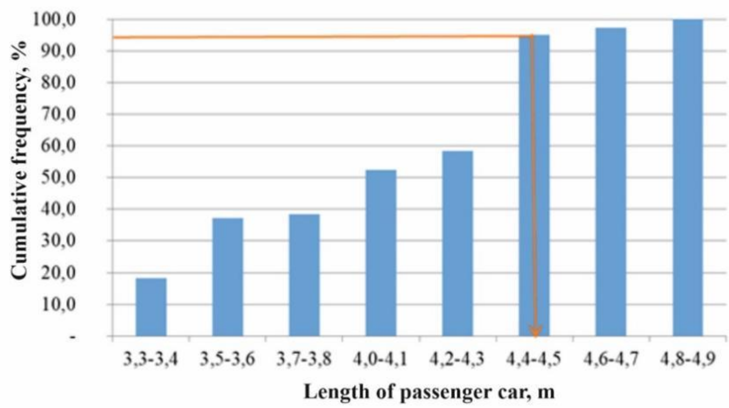


Figure 1. Frequency of passenger car lengths (a) and cumulative frequency (b).

The modal length of passenger cars, when analyzed with 95% confidence, ranges from 4,4 to 4,5 meters, specifically registering at 4,5 meters.

To clarify the aforementioned data research was conducted on passenger car models on Sh.Rashidov street in Jizzakh city. The research was carried out at the intersection of Sh.Rashidov and A.Navoiy streets. According to the results of the day-long study, vehicles with parameters ranging from 4,4 to 4,5 meters are the most commonly used on the city's central streets, accounting for 41% of the total. The remaining percentage consists of other vehicle models. The results of the conducted research align with the data provided by the State Statistics. Figure 2 presents a histogram of the research results conducted on Sh.Rashidov street.

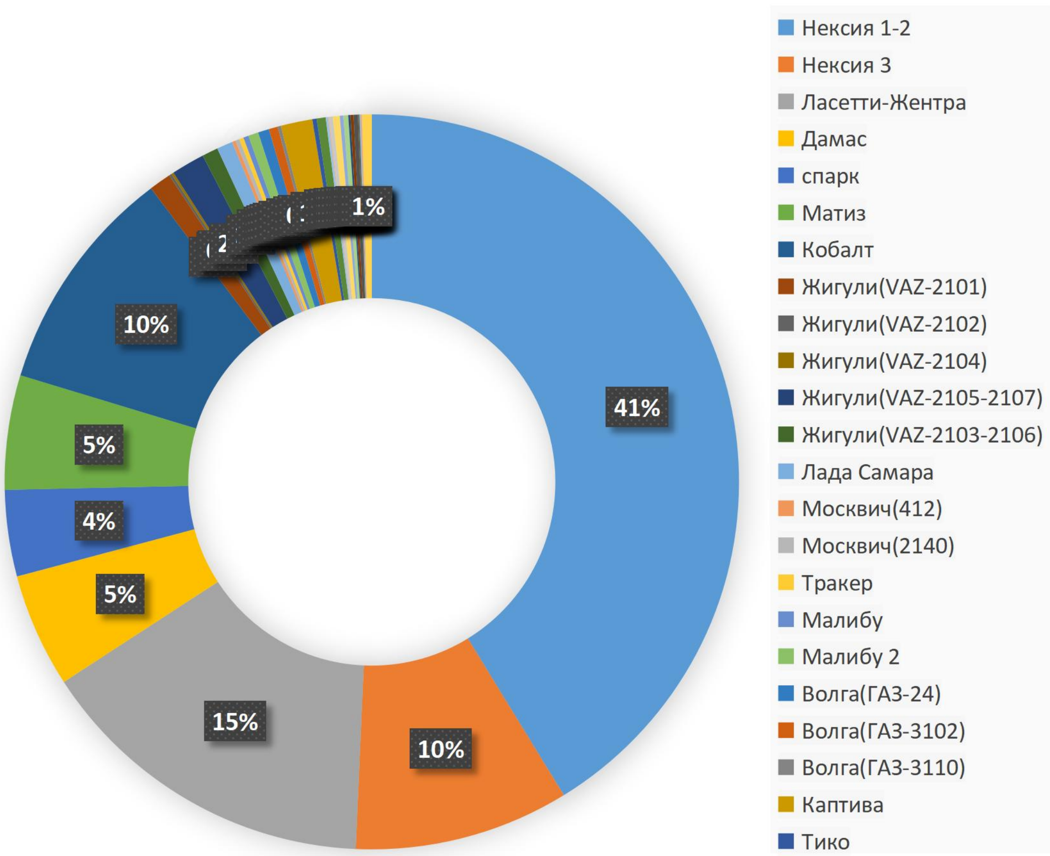


Figure 2. Histogram of the experimental results on passenger car parameters for recommending design vehicle parameters at the intersection on Sh. Rashidov street in Jizzakh city.

Considering the analyses and research work mentioned above, for recommending design vehicle parameters in Group 6 of Table 4, specifically those with dimensions ranging from 4,4 to 4,5 meters are recommended.

Table 5. Recommended design vehicle parameters and types

Category of car	**Type of car**	**Dimensions, mm.**		
		Length	**Width**	**Minimum turning radius**
VI.	Passenger car	4482	1662	4900

CONCLUSION

Analyses of organizing vehicle parking in urban conditions, the study of "design vehicle" parameters in local and foreign documents, and the review of regulatory documents on parking indicate that, due to the rapid global increase in motorization, modern and compact vehicle models are being produced. The dimensions of the "design vehicle" for designing parking spaces are not fully specified. Based on this conclusion, it is necessary to recommend design vehicle parameters for designing parking spaces in urban conditions.

ACKNOWLEDGEMENT

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Framework for Authorisation of Automated Vehicle Testing in Spain

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ABSTRACT

To promote safe, transparent and accountable mobility in the development of automated vehicle technology, Spain has developed a Framework Programme for the Evaluation of Remote Vehicle Safety and Technology. This programme is therefore based on the aim of making progress in defining the policy of safe movement and certification, in addition to improving public transparency related to the safety of automated vehicles, thus allowing the responsible development of this technology.

INTRODUCTION

The Framework Programme for the Evaluation of the Safety and Technology of Automated Vehicles (hereinafter referred to as the ES-AV Programme) establishes a national code for tests and operations with automated vehicles, or driven remotely, intended to operate at any stage prior to their commission on public roads in Spain (covering from prototypes to pre-homologation) updated on 30 June 2025 [1].

The programme provides for the mandatory delivery of reports, both periodic and final and in the event of incidents, which will enable the DGT to assess the safety of evidence and publish basic information on its website, ensuring transparency and public trust.

In addition, with the aim of providing it with a comprehensive approach and management, the Office for the Facilitation of Motor Vehicle Testing (OFVA) has also been established, which will act as a one-stop shop for the management of applications and follow-up tests.

This new framework, which repeals the above instructions (VEH 2022/07 and MOV 2023/13), represents a key step towards the mobility of the future by aligning Spanish legislation with the European Union guidelines as it strengthens the

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framework for the recognition of authorisations of other Member States of the European Economic Area and, at the same time, the requirements for cross-border testing in European corridors with circulation through Spain are relaxed, also expanding the scope of the framework by including vehicle testing with 2 SAE levels and vehicles driven remotely.

ES-AV FRAMEWORK PROGRAMME

The Framework Programme for the Evaluation of the Safety and Technology of Automated Vehicles (ES-AV Programme) is the regulatory framework under which the system of operations and movement for the testing and testing of automated vehicles on roads open to traffic, will be authorized and monitored, the general subject of Royal Legislative Decree 6/2015 [2].

Fig. 1 For authorised testing, automated vehicles shall bear this specific distinguishing mark.

The programme is designed to complement and deepen monitoring, regulation, research and transparency efforts, as well as to support innovation and advancement of technology and the automotive industry. This framework also aims to realize the opportunity to turn Spain into a pioneering and leading space in the field of automated vehicle technology, trying to provide solutions that will help to overcome or alleviate certain deficiencies or externalities of the current transport system:

•**It is committed to transparency and innovation:** It is committed to the transparency of test results as a means of encouraging the deployment of automated vehicles. Support for innovation through a more open and flexible framework.

•**Focus and comprehensive management:** National, European and other access framework. Programme Management Centre and Office of Test Facilitation (OFVA**).**

•**Aligned with European policies:** The authorisation recognition framework for other Member States of the European Economic Area is strengthened. Flexibilization of requirements for cross-border testing in European corridors with circulation through Spain. Action Plan Industry Automotive and Test Guidelines European Commission.

•**Adapted to technological development:** 3 access and authorization systems according to tests already carried out and their results. 3 phases depending on the technological maturity and scope of the tests. Flexibility in authorization adapted to the needs of industry

EXTENSION OF SCOPE

New Technologies and New Vehicles:

•Tests with automated vehicles from levels 2 to 5 SAE, as well as remote driving vehicles, are included within the scope of the Programme.

•Type L, M and N vehicles, as well as others defined in UNECE or DGT regulations.

ACCESS AND AUTHORIZATION SYSTEMS

The Framework establishes three access systems with the consequent obtaining of the authorisation of the tests in relation to the verification and certification procedure for the safety of vehicles and their systems. In order to obtain the authorisation to carry out tests, a number of systems of access and authorisation to the programme are established in relation to the verification and certification procedure for the safety of vehicles and their systems.

EEA recognition system. Linked to the recognition of another authorisation for evidence issued by another State in the European Economic Area. EEA authorisation recognition system: access and authorisation for recognition of the authorisation issued by any State of the European Economic Area, provided that the tests, operations and vehicles subject to that authorisation are similar to those proposed in Spain, without prejudice to the contribution of the application, data on the operational environment, operators and vehicles, results of tests already carried out or other documentation that may be required.

External evaluation system.

The access and authorisation through independent technical evaluation based on the procedure laid down in Appendix 4 to the ES-AV Programme or in the one set out in the European Commission Guide to Testing Automated Vehicles. Based on a technology verification process by an independent evaluator. This procedure is fixed:

- In Appendix 4 ES-AV Programme.
- In the European Commission's Guide on ADS and ADAS tests.

Special System

Special access system is of an exceptional nature and based either on the provision of information and data on real security metrics of operations carried out in any State of the European Economic Area or third countries; or on the assessment of the safety of the vehicle and its systems by any of the procedures set out in the above points or, on an exceptional basis, by means of a self-declaration scheme or an authorisation issued by a third country. Linked to the recognition of tests carried out in third countries.

- These tests are of an exceptional nature.
- Tests are concentrated in other EU or third States.
- Reports should be provided on operations.
- External security assessment, or exceptionally, through a third-country self-declaration or authorization scheme.
- Third countries shall be contracting parties to the United Nations Road Traffic Conventions and the evidence must therefore have conditions similar to those of Spain.

THREE FASES OF TESTS

The Framework also provides for three testing phases, depending on the technological maturity and scope of the data with specific safety, monitoring and technical documentation requirements. Each stage establishes a number of minimum eligibility requirements, and it is the applicant who should indicate the stage in which to participate in the programme in terms of specific technological development.

Phase 1: Controlled

These tests are controlled in limited environments when the technology is newly created or in the process of initial research and development or has only been tested in restricted or simulation environments and therefore needs validation, development and monitoring of its safety. This phase is typical of initial or intermediate stages of technology, prototypes or solutions that operate in the area. Thus, it is related to initial stages or tests in controlled environments.

- Access system: independent evaluation or recognition of authorisation.
- ODD restricted.
- Operational environment up to 3 vehicles.
- Vehicles with level 2 SAE automation are not allowed.
- There must always be a security operator on board.
- They must circulate with Spanish temporary plates.

Phase 2: Extensive

Extensive phase corresponding to intermediate development situations or impulse to technological maturity, and the extent of operating environments. Extensive testing under more real conditions when the technology is already sufficiently developed and tested to be able to operate in broader operational environments and on a continuous basis. It may refer to vehicles for which there are no approval rules, or which intend to obtain their type-approval certificate. It corresponds to intermediate levels of development prior to the commissioning or start-up of the associated service.

- Any access system and also pre-stage operations 1.
- Any ODD.
- Simultaneous operation of up to 10 vehicles is permitted.
- There must always be a security operator on board.

- They must circulate with Spanish temporary or definitive plates.

Phase 3: Pre-deployment

Pre-deployment phase is prior to the commissioning of the vehicle or system. This phase is typical of imminent stages prior to the marketing or commissioning of the service, in vehicles whose driving systems have previously undergone an extensive or similar phase of tests; or systems already approved on which it is intended to perform a contrast of functionalities on roads open to traffic in Spain prior to obtaining the administrative authorisation for circulation; or they are partially approved systems, i.e. with unapproved functionalities or whose approval rules are under way.

- Any access system and also pre-stage operations in phase 1 or 2.
- Any ODD.
- Simultaneous operation of more than 10 vehicles is permitted.
- The on-board safety operator is optional.
- The remote security operator is required.
- They must circulate with Spanish or definitive Spanish temporary plates. Exceptionally, final plates from the EU may also be authorised.
- Vehicles with levels 2 SAE-Pre-Homologation (DCAS) are allowed.

Manufacturers, developers, importers and fleet operators established in Spain or the European Union may participate in the Programme. To this end, they must have prior authorisations, data recording systems, civil liability insurance and trained operators (on board or remote).

Authorized vehicles must bear a distinctive specifically designed for them, either at the lower left angle of the windscreen or in a visible place in the event that the vehicle does not have windscreens.

ES-AV PROGRAMME MANAGEMENT CENTRE (CG-ESAV)

The Management Centre of the ES-AV Programme (CG-ESAV), belonging to the Subdirectorate General for Mobility and Technology Management of the Directorate-General for Traffic, is the body responsible for managing authorizations and admissions to the ES-AV Programme, as well as the monitoring and evaluation of the safety of operations.

External experts may be invited to the DGT, i.e. other administrations or entities in the automotive sector and the technology sector, to carry out the assessment, monitoring and evaluation of the safety of operations, as well as in relation to transparency, exchange of experience and communication.

Finally, the ES-AV Programme Management Centre will publish on the DGT website information on operations and tests under the ES-AV Programme, including basic data, and without any data on technology subject to intellectual or industrial property being disclosed at any time.

OFFICE FOR THE FACILITATION OF MOTOR VEHICLES ON PUBLIC ROADS (OFVA)

OFVA is the one-stop shop for all those interested in participating in the ES-AV Program to:

- Access information on the necessary procedures.
- Perform the required mandatory procedures, including the declarations, notifications or requests necessary to obtain authorization.
- Know the status of processing of applications that have the status of person and receive the corresponding notification of the mandatory procedural acts, if any, and their resolution.
- Communicate incidents and submit reports.

Consultations, the management of applications and the authorizations necessary for admission to the ES-AV Programme and operation on public roads shall be managed through the e-mail programesav.dgt.es.

DATA ON AUTHORISED EVIDENCE

With the focus on increasing transparency, knowledge about the state of the art and the advancement of technology as a means of encouraging and promoting the use of automated vehicles and their benefits, then the main data of the authorized tests and operations can be found. This data will be updated periodically based on ongoing testing.

DOCUMENTS AND RELATED LINKS

•Ongoing regulations: Draft Royal Decree amending the General Regulations on Movement, approved by Royal Decree 1428/2003 of 21 November and the General Vehicle Regulations, approved by Royal Decree 2822/1998 of 23 December on automated driving.

•https://www.dgt.es/export/sites/web-DGT/.galleries/downloads/muevete-con-seguridad/vehiculos-seguros/03_2024_Proyecto_RD_modifica_Reglamento_General_Circulacion_y_Reglamento_General_Vehiculos_conduccion_automatizada.pdf

•Instruction 07/2025 (Spanish)

•https://www.dgt.es/export/sites/web-DGT/.galleries/downloads/muevete-con-seguridad/vehiculos-seguros/report_Instruccion-VEH-2025-07_Programa-ES-AV.pdf

•Instruction 07/2025 (English)

•https://www.dgt.es/export/sites/web-DGT/.galleries/downloads/muevete-con-seguridad/vehiculos-seguros/Instruccion-2025_07_Programme-ES-AV_Automated-Vehicles-Code-for-Testing_EN.pdf

•Tests or research tests of Automated Vehicles https://www.dgt.es/nuestros-servicios/para-colaboradores-y-empresas/vehiculos-de-conduccion-automatizada/pruebas-o-ensayos-de-investigacion/

•Designation of Technology Recognition Centres https://www.dgt.es/nuestros-servicios/para-colaboradores-y-empresas/vehiculos-de-conduccion-automatizada/centro-de-reconocimiento-tecnologico/

•New Infographics Framework for Motor Vehicle Tests https://www.dgt.es/export/sites/web-DGT/.galleries/downloads/muevete-con-seguridad/vehiculos-seguros/Infografias-programa-ES-AV-.zip.a

CONCLUSION

With this new regulatory framework for authorizing and monitoring the testing of autonomous vehicles and remote driving on roads open to general traffic in the country, Spain is positioning itself as a pioneer in the safe integration of vehicles with automated driving systems, promoting technological innovation and improving mobility. The goal is to ensure that these technologies are developed in a safe, transparent and responsible manner, benefiting both industry and citizens.

This updated ES-AV programme is committed to transparency of test results as a means of promoting the deployment of automated vehicles and supports innovation through a more open and flexible framework.

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[2] https://www.boe.es/buscar/act.php?id=BOE-A-2015-1172.

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Call: ERASMUS-EDU-2023-CBHE-STRAND-2
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