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TRAFFIC FLOW PARTICIPANTS AND THEIR INTERACTION: A SYSTEMATIC APPROACH AND OPTIMIZATION OPPORTUNITIES

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Abstract: This article presents a systematic analysis of the types of road traffic participants, their functional roles, and the forms of interaction between them. It also explores the potential for coordinated movement based on modern technologies, particularly AI, B2I, IoT, and GIS. The study highlights existing challenges observed in urban areas of Uzbekistan and proposes solutions for their mitigation.

Keywords: Road traffic participants, interaction, transport safety, V2I, AI, IoT, trajectory, traffic light.

Login. In modern urban transport systems, the interaction between road users - drivers, pedestrians, cyclists, public transport operators, and emergency services - is a complex, multi-layered, and dynamic process that directly affects transport safety and traffic efficiency. Each participant has their own trajectory, speed, priority, and ability to receive information, which requires ensuring their mutual compatibility [1].

These interactions are shaped not only by physical actions but also by visual signals (traffic lights, road signs), information technologies (B2I, IoT), and social factors (transport culture, etiquette). In particular, artificial intelligence (AI), real-time information exchange (V2I) between vehicles and infrastructure, as well as geographic information systems (GIS), allow for the automation and optimization of this process [2, 3].

The problems observed in the cities of Uzbekistan - decreased pedestrian safety, public transport delays, lack of infrastructure for cyclists, and restricted movement of emergency services - require the improvement of interaction mechanisms between participants [4, 5]. Therefore, this article provides a systematic analysis of the types of road users, their functional roles, and forms of interaction. Opportunities for coordinating the movement of participants based on AI, B2I, IoT, and GIS technologies will also be considered. Scientifically grounded proposals will be developed to eliminate existing problems.

Literature review on the topic. Road traffic accidents (RTA) are considered one of the most pressing socio-economic problems worldwide. According to the World Health Organization (WHO), more than 1.19 million people die annually worldwide as a result of road traffic accidents, and about 20–50 million people sustain injuries of varying severity. The majority of accidents occur in cities with high traffic and in congested areas. Therefore, effective traffic flow management and traffic congestion reduction are among the key factors in ensuring road safety [10]. Russian scientists V.V. Silyanov, A.E. Gorev, and Yu.A. Kremenets have conducted in-depth research on the organization of road traffic and traffic flow management. In their works, it is scientifically substantiated that traffic flow density, geometric elements of the road, and intersection throughput significantly influence the risk of accidents [11–13].

Methodology. In this study, a comprehensive methodological approach was applied to analyze the interaction between road users, identify existing problems, and evaluate optimization opportunities

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based on modern technologies. The study was conducted on a multidisciplinary basis - technological (AI, B2I, IoT), social (behavioral, cultural), legal (legislative) and spatial (GIS, trajectory) aspects were jointly analyzed. The functional role, trajectory characteristics, and forms of interaction of each participating group were modeled separately. The database relied on primary and secondary sources: primary sources included statistical reports from the Main Traffic Safety Department of the Ministry of Internal Affairs of the Republic of Uzbekistan (2022-2024), data from city transport departments, traffic light phases, and maps of pedestrian crossings; secondary sources included international scientific articles (Markkula et al., Dey et al.), UNECE and ETSC documents, as well as urbanistic models and simulation platforms. This approach served to ensure the scientific validity and practical application of the research results.

Results. Analysis of interaction between road users is an important scientific direction in transport safety, traffic efficiency, and urban infrastructure planning, requiring a multidisciplinary approach: technological (AI, B2I, IoT), social (behavioral, cultural), legal (legislative), and spatial (GIS, trajectory) aspects are studied together. The interactive action model developed by Markkula et al. (2020) explains behaviors formed based on visual and social signals between participants, while Dey et al. (2025) provides a scientific basis for trajectory analysis and traffic light phase optimization by simulating dyadic interaction. While the UNECE (2024) and ETSC (2023) documents examine the impact of AI and B2I technologies on transport safety and priority mechanisms for emergency services, articles regularly published in the Traffic Safety Research (TSR) journal serve as an important resource for analyzing accident statistics, safety strategies, and technological innovations [3, 4, 5].

Classification and functions of road users.

Road users are individuals and entities actively involved in the transport system, each of which plays a crucial role in ensuring traffic safety, efficiency, and environmental sustainability. They are functionally divided into various groups:

1) Drivers are persons operating passenger cars, trucks, public and special service vehicles who ensure the safe and efficient operation of the transport system by complying with traffic rules, being attentive to other participants, and acting in coordination with traffic lights, road signs, pedestrians, cyclists, and emergency services.

2) Pedestrians are participants consisting of adults, children, persons with disabilities, and public transport passengers who move in coordination with drivers, traffic lights, pedestrian crossings, and public transport by crossing the road, using stops, and choosing a safe trajectory.

3) Cyclists and micromobile vehicle owners are users of bicycles, electric scooters, and electric bikes who move along designated lanes as eco-friendly means of transportation and participate in coordination with vehicles, pedestrians, and road infrastructure.

4) Public transport operators - consisting of bus, tram, metro and shuttle drivers and system operators, who perform the task of safe and efficient transportation of passengers on designated routes and act in coordination with stations, drivers, pedestrians and traffic lights.

5) Emergency services - consisting of ambulance, fire safety, and police vehicles, which perform the function of rapid response and priority in emergency situations and ensure priority in coordination with all participants, V2I systems, and traffic lights.

6) Autonomous vehicles consist of cars and robotic vehicles controlled by artificial intelligence, which move safely through sensors and algorithms and interact with infrastructure, other vehicles, and pedestrians based on real-time information exchange through B2I and IoT technologies.

The correct classification of road users and the determination of their functional roles serve as an important scientific basis for optimizing the transport system, increasing safety, and implementing

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modern technologies. The unique trajectory, speed, priority, and information reception characteristics of each group shape their interaction mechanisms.

Forms and mechanisms of interaction. Interaction between road users is a complex system aimed at ensuring traffic compatibility, safety, and efficiency, implemented through several forms and technological mechanisms. Each participating group has its own trajectory, speed, priority, and ability to receive information, which determines their interaction [1, 2, 6].

Physical impact is a form of interaction based on the intersection of trajectories, movement directions, and speed differences, in which the risk of collision, distance maintenance, turning, and stopping play an important role; the level of danger increases significantly, especially in the absence of a traffic light or sign at points where pedestrian and vehicle trajectories intersect.

Visual impact is a form of interaction carried out through traffic lights, road signs, lines, and pedestrian crossings, where participants rely on these visual signals to coordinate movement, and its effectiveness directly depends on the placement of signs, lighting, and visibility.

Information interaction is an interaction between vehicles and infrastructure through B2I (Vehicle-to-Infrastructure), IoT (Internet of Things), and AI (artificial intelligence) technologies, formed through the real-time exchange of information such as speed, trajectory, traffic light phase, and hazard level, which plays a crucial role in automatically prioritizing emergency services.

Social influence is a form of interaction formed on the basis of transport culture, behavioral norms, and rules of etiquette; examples include cases where a driver gives way to a pedestrian or a cyclist moves along a designated lane. Information campaigns, advocacy, and educational processes are essential to enhance this impact.

The forms of interaction between road users—physical, visual, informational, and social—are inextricably linked, and their coordination ensures the safe and efficient operation of the transport system. Modern technologies allow for the automation and optimization of these influences, while social culture ensures their sustainability. These impacts are coordinated through transport infrastructure and management systems.

Coordination through modern technologies. Road traffic coordination through modern technologies is a system for safe and effective coordination of participant movement through automated control, real-time monitoring, and information exchange.

Automated Control Systems (ACS) are a technological approach that ensures real-time optimization of traffic light phases through intelligent transport systems, as well as the adaptation of road signs, traffic lights, and traffic routes depending on the level of congestion; the resolution of the Cabinet of Ministers of Uzbekistan defines measures to increase road safety through the implementation of these systems [7, 8].

V2I and IoT technologies are a modern approach that operates through Vehicle-to-Infrastructure (V2I) systems that facilitate the exchange of information between vehicles and traffic lights, stations, and other infrastructure elements, as well as Internet of Things (IoT) sensors that determine the trajectory, speed, and risk level of vehicles and pedestrians, playing a crucial role in automatically prioritizing emergency services.

Artificial intelligence-based analysis is a modern approach aimed at optimizing the traffic flow by analyzing the dynamics of vehicle participants through AI algorithms, predicting the probability of trajectory intersection, predicting driver behavior, adjusting traffic light phases, and defining safety zones.

Mobile applications and digital platforms are modern technological solutions that allow road users to provide traffic alerts, accidents, and road closures through navigation applications such as

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Yandex.Navigator and Google Maps, as well as to coordinate passenger movement in public transport systems through electronic tickets, GPS tracking, and real-time stop data [8, 9].

Existing problems in coordinating the transport system in the context of Uzbekistan.

1. Conflicts between pedestrians and drivers. In many cities and districts, the improper placement of pedestrian crossings, intersections not coordinated with traffic lights, and the lack of signs reduce pedestrian safety and lead to conflict situations with drivers.

2. Lack of infrastructure for cyclists. Due to the insufficient implementation of special bicycle paths, designated traffic zones, and safety measures, cyclists are forced to participate in the general flow of traffic, which increases the level of risk.

3. Public transport delays and lack of priority. Buses and shuttles get stuck in traffic jams, lack of priority in traffic light phases, and slow real-time monitoring based on GPS cause delays and inconvenience for passengers.

4. Restrictions on the movement of emergency services. The lack of dedicated lanes and automatic priority systems for ambulance, fire safety, and police vehicles limits their rapid access to emergency situations.

5. Poor technological integration (AI, B2I, GIS). Modern technologies such as artificial intelligence, B2I (Vehicle-to-Infrastructure), and GIS (Geoinformation Systems) are not fully integrated into the transport system, which reduces the level of coordination, security, and monitoring.

Proposals and solutions.

1. Creation of separate paths for pedestrians and cyclists. To ensure traffic safety and reduce conflicting trajectories, special lanes must be designated for pedestrians and cyclists. This not only increases safety but also encourages the use of eco-friendly vehicles.

2. Testing of AI and B2I technologies (pilot projects). By implementing pilot projects to implement artificial intelligence and Vehicle-to-Infrastructure (V2I) technologies in major cities such as Tashkent, Samarkand, or Andijan, real-time control, traffic light phase adjustment, and priority for emergency services can be tested.

3. Control of traffic light phases based on trajectory analysis. By adapting traffic lights based on algorithms that analyze the trajectories of vehicles and pedestrians in real time, it is possible to reduce traffic congestion and minimize the risk of collisions.

4. Strengthening transport ethics and information campaigns. To improve the behavior of drivers and pedestrians, to improve the culture of road traffic, it is necessary to regularly conduct propaganda work through the media, social networks and educational institutions.

5. Adapting the regulatory framework to modern technologies. Legal support for the integration of AI, B2I, IoT, and GIS technologies into the transport system requires updating existing legislation and developing technical regulations and standards.

Conclusion. Systematic analysis of interaction between road users and coordination through modern technologies is a crucial factor in increasing transport safety and efficiency. In the context of Uzbekistan, reforms in this area require a combination of technological, organizational, and social approaches.

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