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Issue Article

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METHODS FOR MANAGING AND DEVELOPING TRANSPORT NETWORKS IN CITIES

Abstract*: This article describes traffic flow management methods currently implemented in urban areas. The fundamental principles of these methods are analyzed. Additionally, the paper presents information on the interrelationships between various traffic flow management methods and states, as well as on improving the efficiency and automation of traffic flow management.*

Key words*: automotive transport, transportation networks and flows, operation, new information technologies in transportation networks.*

Language*: English*

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Introduction

The issue of improving traffic organization in cities is addressed through the coordinated movement of traffic flows. Implementing modern methods of traffic flow management ensures the achievement of maximum efficiency in the short term under existing conditions and allows for the full utilization of urban road network capabilities. This matter has a complex national character, and its resolution is carried out in accordance with the decisions of the Uzbekistan government and regional legislative bodies.

Furthermore, the Resolution No. 415 of the Cabinet of Ministers of the Republic of Uzbekistan dated 30.07.2022 "On the introduction of scientific and methodological support in the field of road safety, regulation of operational and installation activities on roads, and the implementation of the practice of maintaining the "Safe Road' index" provides specific guidelines for optimization [1].

On February 16, 2023, Resolution No. 59 of the President of the Republic of Uzbekistan "On Measures to Reform the Public Transport System" was adopted [2]. In accordance with the resolution, a roadmap for improving the public transport system in the city of Nukus has been developed.

Experimental studies conducted in several cities of the country have repeatedly confirmed that the implementation of automated traffic management systems using advanced methods of traffic flow control is highly effective within a short period (1-2 years). For a city with a population of about 1 million, a total annual economic benefit of several billion is achieved by reducing vehicle delays, decreasing fuel consumption, and increasing traffic speed.

Currently, more than 100 major (various types) and 30 city-wide automated traffic management systems are in operation.

In the future, by 2026, in accordance with government decisions, it is planned to implement automated traffic control systems in all cities with a population exceeding 300,000. These systems will be based on standard complexes developed through programs agreed upon by the Government of Uzbekistan and the Main Directorate of Road Safety of the Ministry of Internal Affairs [3-4].

If this system is implemented, it will have significant social importance as air pollution could decrease by 10-25 percent and the number of road accidents could reduce by 10-15 percent. The greatest effect is achieved through coordinated management, as the impact on traffic flows is calculated and formed while taking into account changes in traffic intensity.

As the scale of implementing coordinated traffic flow management methods and tools expands and transitions to an industrial scale, the need to develop comprehensive theoretical and methodological support for these methods and tools is becoming increasingly evident. The traffic flow management methods currently used in practice can be grouped as follows: adaptive management, formative management, and strictly coordinated management.

Adaptive control methods primarily affect individual vehicles and require well-equipped automated traffic control systems with transport detectors.

Formative control influences a portion of the traffic flows and does not require the use of numerous transport detectors.

Strictly coordinated control ensures the continuous movement of traffic flows, but does not affect the flows themselves and does not require the use of transport detectors.

In a bound state, traffic flows exhibit properties of an indivisible solid body. In this state, the breakdown and reformation of the flow is practically impossible, and the speed of movement for all group participants is uniform. Thus, for each state of traffic flows, in accordance with its specific characteristics, the following optimal control methods can be determined:

- a free state with characteristics of independence - flexible control;

- a group state with adaptive properties - formative management;

- a connected state with indivisible properties - strictly coordinated preventive control.

Let us examine in detail the relationship between control methods and various states of traffic flows.

Free movement. In the transport network, we distinguish road sections (time intervals) where vehicles move in a free regime. Research and practice show that for low-intensity flows, traffic light control that records vehicle arrival times at intersections and changes traffic light operating modes according to the random traffic process is both possible and effective. Such control is called feedback control of the flow. In reality, this is the fastest control method in the system (feedback delay is measured in seconds), as it responds immediately to the appearance of each individual transport unit.

The free movement of traffic flows in regulated intersection areas closely follows the Poisson distribution. This occurs due to the minimal impact of traffic light signaling modes at adjacent intersections on the flow structure. This principle is crucial for regulatory practice, as it implies that under free-flow conditions, intersections are operationally independent. In such circumstances, intersections can be treated as discrete entities. Consequently, we refer to traffic management under free-flow conditions as adaptive (local) control. Based on the selected criterion, we consider the primary objective of local control to be determining traffic light signaling modes that minimize the total delay in serving vehicles at the intersection.

The road transport network of a large city always experiences high traffic intensity during morning and evening hours.

Group movement pattern. Let's consider the section of the network where the traffic flow moves in a grouped manner. In this case, the main limiting factor for control is the network's throughput capacity.

Considering that when traffic intensity increases on road sections, a group traffic pattern naturally emerges, the essence of traffic light signal management should be to serve groups (clusters of vehicles) rather than individual vehicles (as in public service systems). The regular alternation of green and red traffic light durations leads to the group traffic flow transitioning into a more compact form after being served at intersections. In group traffic mode, intersections in the network become interconnected from a control perspective, as the appearance of the "cluster" passing through an intersection determines the operating mode of the next intersection along the traffic direction. For this reason, we refer to group flow management as coordinated or network control. Since coordinated control responds to the formation of "clusters" rather than individual vehicles, its discretization step is measured in minutes. Optimal coordinated control is defined as a state where the set of control parameters for all intersections in the considered network minimizes the total delay of vehicles across all traffic directions at the intersections.

Since the city's most important highways with high traffic volumes are incorporated into the coordinated network, such management is considered the central component of any traffic control system.

Linked (mandatory) traffic mode. Now let's examine the road situation where traffic flows in certain sections of the network are approaching saturation levels. Based on known traffic intensities, we select control parameter values that correspond to the minimum total average delay of flows (coordination mode) at the network intersections. Clearly, the only way to address this issue is to activate the permissive signal in advance. This type of control is considered "stricter" for vehicle drivers compared to local or coordinated control. This strictness is determined by the fact that the control system must eliminate the possibility of braking for a group of vehicles. [5-6].

Analysis of the equipment level of automated traffic management systems operating in Uzbekistan over a twenty-year period has shown that the choice of traffic flow management method has always depended on the funds allocated for system development. It should also be noted that the results of fifteen comprehensive assessments of automated traffic control system equipment revealed a weak correlation between control methods and their quality. Adaptive control is typically ineffective at high traffic intensity, while rigidly coordinated control is not always effective at low traffic intensity.

To facilitate further analysis, let's refer to the fundamental transport diagram:

$$\boldsymbol{\lambda = p * V} \quad (1)$$

where $\boldsymbol{\lambda}$ is traffic intensity; $\boldsymbol{p}$ is the density of traffic flows; and $\boldsymbol{V}$ is the speed of traffic flows [7-8].

Analysis of this relationship demonstrates that in urban areas, under conditions of limited traffic speed (60 km/h), an increase in traffic intensity results only in increased traffic density. Taking into account the presence of intersections on city thoroughfares, it becomes evident that traffic density will increase by approximately 50%. Consequently, as traffic intensity rises, traffic flows rapidly assume a columnar pattern, making overtaking impossible due to the minimal distance between consecutive vehicles.

Based on the above, one of the advanced methods of traffic flow management is the implementation of automated traffic control systems, which leads to achieving high-tech methods for combating traffic congestion (Figure 1) [9].

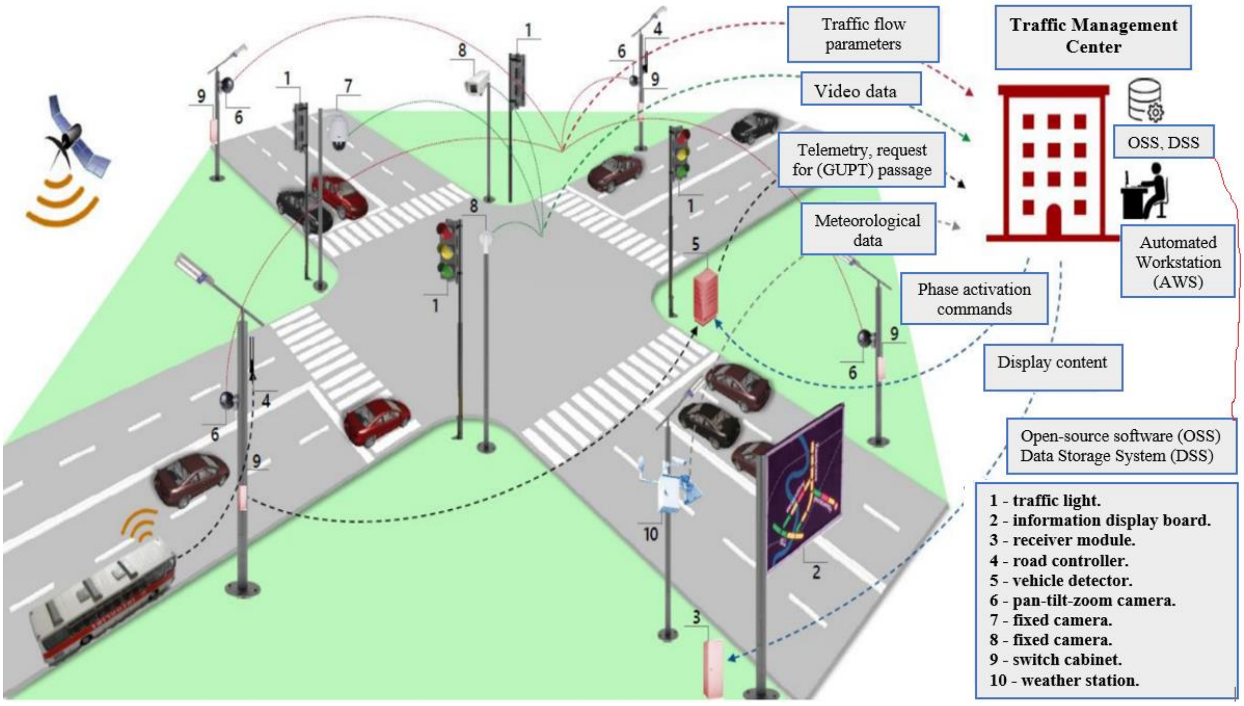

Figure 1. Composition and schematic diagram of automated traffic control systems.

The technological features of automated traffic control systems are as follows:

• Centralized control of traffic lights in manual and automatic modes;

• Real-time monitoring of traffic flows using transport detectors;

• Surveillance of city road situations through video monitoring;

• Continuous monitoring of the operational status of traffic controllers, transport detectors, and video cameras;

• Maintain a registry of peripheral equipment (road controllers, traffic sensors, video surveillance cameras);

• Display peripheral objects on a map-based interface;

• Manage system access rights;

• Ensure traffic safety;

• Improve street and road network parameters, reduce traffic delays;

• Enhance the environmental situation.

Based on the above, the following recommendations have been developed:

- Studying international experience in addressing the aforementioned problems and familiarizing oneself with comprehensive measures aimed at solving transport infrastructure issues in various megacities around the world is of great importance for the development of this sector;

- Strict adherence to the rule of Urban Planning Standards and Regulations 2.01.07-03 - "infrastructure first, then construction";

- Study of the city's master plan and development of the residential zone with small residential blocks, ensuring the side length between street intersections does not exceed 250 m in the street-road scheme [10];

- Transition to automated traffic management systems in all cities with a population of more than 300,000 people;

- Development of scientifically based schemes for the prospective planning of cities' street and road networks, which includes optimal planning of urban traffic flows, organization of transport hubs based on best practices to improve the city's connection with external transit roads, and other related measures.

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