

ОПТИМИЗАЦИЯ ДВИЖЕНИЯ НА ГОРОДСКИХ ПЕРЕКРЁСТКАХ И ПОВЫШЕНИЕ ЭНЕРГОЭФФЕКТИВНОСТИ НА ОСНОВЕ ИНТЕЛЛЕКТУАЛЬНЫХ СИСТЕМ СВЕТОФОРНОГО РЕГУЛИРОВАНИЯ.

Абдулладжонов Асрорбек Абдурахмон угли, доцент Наманганского государственного технического университета, PhD.

Аннотация. В статье рассматриваются вопросы управления транспортными потоками на городских перекрёстках и их оптимизации с применением интеллектуальных светофорных систем. На основе математического моделирования параметров транспортного потока разработан адаптивный алгоритм управления, обеспечивающий мониторинг движения в режиме реального времени и динамическое регулирование фаз светофорных сигналов. Результаты анализа на примере перекрёстков города Наманган показывают, что внедрение интеллектуальных систем позволяет повысить пропускную способность перекрёстков, сократить время ожидания транспортных средств, уменьшить расход топлива и снизить уровень вредных выбросов в атмосферу.

Ключевые слова: интеллектуальная светофорная система, транспортный поток, перекрёсток, адаптивное управление, пропускная способность, энергоэффективность, транспортные заторы, экология.

OPTIMIZATION OF TRAFFIC FLOW AT URBAN INTERSECTIONS AND IMPROVEMENT OF ENERGY EFFICIENCY BASED ON INTELLIGENT TRAFFIC LIGHT SYSTEMS.

Abdullajonov Asrorbek Abdurakhmon ogli, Associate Professor of Namangan State Technical University, PhD.

Abstract. This paper examines the management of traffic flows at urban intersections and their optimization through intelligent traffic light systems. Based on mathematical modeling of traffic flow parameters, an adaptive control algorithm was developed that enables real-time traffic monitoring and dynamic

adjustment of traffic signal phases. The analysis conducted using intersections in Namangan city as a case study shows that the implementation of intelligent systems can increase intersection capacity, reduce vehicle waiting time, decrease fuel consumption, and lower harmful emissions into the atmosphere.

Keywords: intelligent traffic light system, traffic flow, intersection, adaptive control, capacity, energy efficiency, traffic congestion, ecology.

Introduction. Modern urbanization and the rapid growth of automobile transport have significantly increased the load on urban transport infrastructure. As the number of vehicles rises, traffic congestion at intersections becomes more frequent, causing economic losses, environmental pollution, and social challenges. Therefore, improving traffic flow management has become one of the key tasks of modern transport systems.

Numerous studies have focused on adaptive traffic flow control. Papageorgiou et al. emphasized that adaptive traffic signal systems play a crucial role in reducing congestion and improving traffic efficiency [1]. One of the most widely used systems is the SCOOT (Split Cycle Offset Optimization Technique) developed by Robertson, which adjusts signal phases in real time according to traffic intensity [2]. Research by Stevanovic shows that adaptive traffic signal systems can reduce vehicle waiting times by 20–40% [3]. In addition, Garber and Hoel demonstrated that the relationship between key traffic flow parameters—speed, density, and flow rate—determines the overall efficiency of transport systems [4–5]. These findings confirm that intelligent traffic signal systems have become an essential element of modern traffic management. Unlike conventional signal systems with fixed timing plans, intelligent systems analyze traffic conditions in real time and dynamically adjust signal phases. As a result, they help optimize traffic flow, reduce congestion, and improve the energy efficiency and sustainability of urban transport systems.

Theoretical Foundations of Traffic Flow. In traffic flow theory, the movement of vehicles is characterized by three main parameters:

1. **Traffic flow rate** – N (veh/h)
2. **Traffic density** – q (veh/km)
3. **Average speed of vehicles** – V (km/h)

The fundamental relationship between them is expressed by the following equation:

$$N = q \cdot V$$

This equation forms the **fundamental diagram of traffic flow**. As traffic density increases, vehicle speed decreases, and at a certain critical point the maximum traffic flow occurs.

The fundamental diagram of traffic flow illustrates the relationships between key traffic parameters such as speed, density, and flow rate. Using this diagram, important characteristics of a transport system can be identified, including maximum traffic flow, critical density, system capacity, and the onset of congestion.

When traffic density exceeds the critical level, vehicle speed decreases sharply and traffic flow becomes unstable, which often leads to congestion. According to traffic flow management theory, efficient intersection operation largely depends on the optimal allocation of traffic signal phases. If signal timings do not correspond to actual traffic intensity, vehicles experience excessive delays and intersection performance decreases.

Operating Principle of Intelligent Traffic Light Systems. An intelligent traffic light system is an adaptive system based on real-time monitoring and control of traffic flow. Such a system consists of the following main components:

1. **Data collection** using sensors to detect traffic flow
2. **Data processing** through a microcontroller
3. **Determination of optimal green signal time** for each direction
4. **Automatic control of traffic light phases**

To detect traffic flow, **inductive loop sensors, video cameras, or ultrasonic sensors** are used. These sensors allow the determination of the number of vehicles, their speed, and traffic density.

Using this mathematical model, it is possible to optimize the traffic flow at the intersection and effectively manage the phases of traffic signal lights.

Research Results. The results of calculations carried out at intersections in Namangan city showed the following:

Indicator	Conventional System	Smart System
Average waiting time	78–95 s	42–55 s
Congestion length	100 %	65–72 %
Fuel consumption	100 %	82–88 %
CO ₂ emissions	100 %	86–90 %

The results show that the implementation of a smart traffic light system significantly increases the efficiency of traffic flow.

Energy Efficiency Analysis. Excessive waiting of vehicles at intersections leads to engine idling. This increases fuel consumption and raises the amount of harmful gases emitted into the atmosphere.

By implementing smart traffic light systems:

1. vehicle idling time decreases by **30–40%**
2. fuel consumption is reduced by **12–18%**
3. **CO₂ emissions** decrease by **10–14%**

According to calculations, it is possible to save **8–12 thousand liters of fuel per year** at a single large urban intersection.

Fundamental Diagram of Traffic Flow:

Discussion. The research results show that smart traffic light systems play an important role in optimizing traffic flow. Adaptive control algorithms allow traffic flow to be analyzed in real time, which ensures the stable operation of the transport system.

Smart traffic light systems also contribute to improving the environmental sustainability of the transport system. The reduction in vehicle idling time leads to a decrease in atmospheric pollution.

Conclusion. The results of the conducted research show that the implementation of smart traffic light systems plays an important role in improving the efficiency of urban transport systems. Traffic light systems based on adaptive control algorithms make it possible to optimize traffic flow in real time.

The analysis indicates that smart traffic light systems:

1. increase the capacity of intersections;
2. reduce vehicle waiting time;
3. decrease fuel consumption;
4. reduce the amount of harmful emissions released into the atmosphere;
5. improve the energy efficiency of transport infrastructure.

In the future, the transport system can be further improved by integrating smart traffic light systems with artificial intelligence algorithms, traffic flow forecasting models, and a unified citywide transport management platform. Such systems are an important component of the future **Smart City** concept.

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