Evaluation of the effectiveness of the adaptive traffic management system for its development and interaction with electric transport

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Abstract. Transport infrastructure is one of the important directions of urban environment sustainable development. The increase in the area of cities necessitates the implementation of measures aimed at improving the quality of transport services. This causes the development of intelligent transport systems, which allow to reduce the load on the transport network. However, the development of these systems in the Russian Federation lags behind the world experience and for the regulation of the traffic light it necessary the operator's intervention and the connection of the peripheral device with the traffic control center. Therefore, the use of these systems is difficult in remote areas such as the intersections that connect the industrial and residential parts of the city. These intersections, as a rule, have unstable transport demand in time and directions, which causes "unjustified" downtime of vehicles during the red light in the main direction. This article presents the adaptive traffic management system, which is autonomous and allows changing the cycle of traffic light regulation in remote territories. In the future, the plan of the development of this system is aimed at developing a new type of detector which communicates with the electric car.

1. Introduction

At the present time, the peculiarity of the socioeconomic state of the country is the concentration of the population in the centers of the Russian Federation subjects [1]. This causes the emergence of a number of negative living conditions, which are associated with intense pollution of the atmosphere, the expansion of urban areas, therefore, by removing the centers of attraction of the population [2]. The solution of these problems is the concept of sustainable development of these settlements [3]. Its main provisions are a long-term plan for changing economic and production activities, according to which a scheme for city's engineering infrastructure is developed, in particular transport.

The increase in the area of cities causes a decrease in the quality of transport services for the population, for the increase of which it is necessary to carry out activities. This is due to the reconstruction of the existing road network, the decentralization of places of employment and recreation, as well as the improvement of the organization of road traffic vehicles, both in the urban environment and for interaction beyond its borders [4–6]. However, the first two types of measures require large capital costs and are difficult to reconstruct the existing part of the city.

Improving the organization of road traffic is the most common method of increasing the capacity of the road network, and, therefore, reducing the time spent on moving. This is due to the high proportion of equipped intersections with traffic lights and the ability to search for an optimal cycle
of their regulation at minimum cost [7]. However, during the last decade, intelligent and adaptive transport systems that increase the capacity of the intersection in the absence or partial intervention of the operator by automatically searching for the optimal traffic signal regulation cycle have been widely applied [8, 9]. Its local project is automated traffic management systems that contribute to increasing the carrying capacity of intersections, reducing the time of vehicle delays and improving the ecological situation of the environment [10]. However, these devices have, from a technical point of view, some drawbacks that lie in the mandatory presence of the operator, in the constant interaction of peripheral equipment with an automated workplace and high capital costs. This leads to some limitations in the area of application of these systems, in particular, this is the lack of possibility of their installation in remote areas, as well as at intersections with low or unstable transport demand in directions and time.

At the present time, an increase in the ecology of the urban environment consists not only in discouraging the population of using personal transport, increasing adaptability of vehicles to the required standards, reducing the time for vehicle delays to red light, but also in creating industrial zones in remote areas that adjoin the boundaries of a locality [11–15]. This causes the development of a new transport infrastructure, which is the connecting element of the places of employment and rest. Increased safety in these areas is achieved by their equipment with traffic lights, which is explained by low capital costs [16]. Therefore, we can often observe the intersection of the road network with entrances and exits from enterprises with a lack of transport demand from a secondary direction, which according to GOST R 52289-2004 (with changes from 2015) should be equipped with traffic lights. This leads to the formation of ineffective delay of vehicles during red light in the main direction, in the absence of transport demand for a secondary. The solution to this problem can be an adaptive traffic management system that will reduce the operating time of the red light in the main direction and increase the capacity intersection. Therefore, the goal of the work is the development of an adaptive traffic management system with low capital costs and an assessment of the possibility of its installation in remote areas, namely at intersections with unstable transport demand in time and directions.

2. Methodology
In Russia, the development of intelligent transport systems lags behind world experience, which is due to the uneven design of infrastructures by regions and the historical and architectural features of the urban environment [17–20]. Currently, as a rule, first and second generation systems that require operator intervention in the management process are applied in the Russian Federation. This causes the lack of autonomy of the system and the possibility of its installation in remote areas, in particular at entrances and exits from enterprises or remote administrative facilities. The solution to this problem is the use of an adaptive traffic management system that includes a detector and a controller with a program for autonomous control of the traffic light. At the present time in Russia, such systems are used to pass a pedestrian on regulated transitions and to provide an advantage when turning the vehicle. The efficiency of these systems is estimated with the help of indicators: the number and severity of the road accident, the capacity of the road network, transport delays, the number of vehicle stops, the length of the queues ahead of the intersections, the time of the trip, the speed of the message. However, as a rule, the leading indicator is the average delay of vehicles, which is due to the ability to analyze the nature of the operation of intersections and their capacity. Calculation and forecast of this value for intersections with unstable transport demand in time and directions is difficult, therefore earlier the authors of this work proposed an indicator that estimates the proportion of inefficient phases of traffic lights. It is defined as the ratio of the number of green light for which there is no transport demand to the total number of green light:

\[ \eta_{t,r} = \frac{N_{i,r,p}}{N_{r,p}} \] (1)
where \(N_{r,p}\) – number of green light with no transport demand; \(N_{r,p}\) – total number of green light in this direction.

It allows you to analyze the efficiency of a traffic light and evaluate the rationality of its equipment with an adaptive traffic management system.

The paper [21] is defined the area of application of an adaptive pedestrian management system. The main indicator of the assessment is the delay of vehicles and pedestrians, as well as the intensity of their movement. The ratio of the intensity of pedestrian traffic to the intensity of vehicles at which it is recommended to install a pedestrian ringing device is 0.42. Based on the analysis of this work and according to GOST R 52289-2004 (with changes from 2015), where the traffic intensity of cars is indicated, at which a traffic light object with a rigid regulating mode is installed, the study was conducted for an adaptive traffic management system. This value is 0.5 for the application of a rigid mode of traffic light regulation.

The number of phases in which there is no transport demand depends on the traffic intensity and impacts on road capacity, that is, the greater the traffic intensity of vehicles, the less the number of phases not involved and the less the indicator of ineffective phases of traffic lights. Therefore, the value of 0.5 was proposed as the lower limit of the developed indicator. When it is less than 0.5, then the operation of a traffic light with a rigid control mode is effective. This value is the basis for assessing the effectiveness of traffic signal regulation at intersections with unstable transport demand in time and direction. The scope of the adaptive traffic management system is limited by the values of the proportion of ineffective phases of the traffic light equal to 0.5 or more.

Increasing the efficiency of intersections with unstable transport demand in time and directions can be achieved by increasing the capacity, reducing the time of delays of vehicles along the main road (with the prevailing transport demand during the day), and, consequently, by reducing the inefficient phases of the green light from the secondary direction. This necessitates the need to equip crossroads with a system that will include a red light when transport demand occurs from a secondary direction. Thus, the purpose of the experiment is to identify the places of application of the developed adaptive traffic management system and to assess the effectiveness of its application.

### 2.1. Research of application of adaptive traffic management system

The main criterion for determining the scope of an adaptive traffic management system is the proportion of ineffective phases of traffic lights. Initially, researchers at each of the proposed intersections in the morning, afternoon and evening time were counted the number of green light, in which there was no transport demand, and their total number in the direction in question. Further, for each intersection, the proportion of inefficient phases of the traffic light was calculated, which made it possible to determine in Tyumen the necessary locations for the installation of an adaptive traffic management system.

### 2.2. Assessment of the effectiveness of the adaptive traffic management system

The experimental study was carried out at the intersection, which was analyzed to assess the effectiveness of the traffic light object. As a result of the analysis of the data of the previous stage, the authors found that the traffic signal regulation of this intersection is ineffective. Therefore, it was chosen as a test site. The intersection scheme, which was selected for testing, is shown in Figure 1.

This intersection was equipped with an adaptive traffic management system, which was called the "Calling Automobile Device". The system includes a video detector and a controller that allows sending control signals to turn on the red light to the main directions 1 and 2 in case of a transport demand from a secondary 3–6 using the specified program. To assess the effectiveness of the application of this system, some indicators were revealed before and after the equipment of the traffic light of the developed system. This was the capacity in the main direction, the time of vehicle delays and the decrease in fuel consumption, spent in idle vehicles on an ineffective red light, and, consequently, emissions of harmful substances and carbon dioxide into the atmosphere.
3. Results

3.1. Research of application of adaptive traffic management system

Tyumen was chosen for research, since it is a historically established settlement. The intensive development of its transport infrastructure, which provides an increase in the level of road safety, leads to a large number of intersections equipped with traffic lights. The city's territory can be divided into several zones: administrative and residential, and industrial zones, as shown in Figure 2.

![Figure 2. The zoning of Tyumen](image)

The central part of the city is an administrative and residential zone and the semi-circle around it on the boundaries of the city territory are industrial sites: Antipinsky refinery, UMMC Steel, reinforced concrete products plant ZHBI-5. These large enterprises are the centers of industrial zones, in which
there are also some medium and smaller companies. When the transport infrastructure that connects the places of employment and recreation was created, intersections were equipped with traffic lights to ensure road safety. This led to the formation of intersections with unstable transport demand in terms of time and directions. However, this situation is typical not only for industrial zones, but it is also observed for municipal institutions and large sports facilities. The expected intersections that need to be equipped with an adaptive traffic management system were analyzed using the indicator of the proportion of ineffective phases of the traffic light, proposed by the authors, which is reflected in Figures 3 and 4.

Only part of the intersections with unstable transport demand in time and directions were analyzed during the experiment. Also, the authors identified the most characteristic places of application of the adaptive traffic management system. These are departures from adjacent territories, in particular hospitals, administrative buildings; crossing, which connect the major sports facilities, industrial enterprises with the city's road network. One of the crossroads analyzed, which is the section road that connects the large industrial enterprise (reinforced concrete products plant ZHBI-5) with the city's road network, was chosen to assess the effectiveness of the adaptive traffic management system.

3.2. Assessment of the effectiveness of the adaptive traffic management system
The average traffic intensity in the main directions 1 and 2 at this intersection is 1755 car/hour, while the traffic light regulation of this intersection is performed within 15 hours. As a result of the analysis of previous studies, the authors found that the proportion of ineffective phases of traffic signal regulation is 0.89 and 0.86 respectively for directions 3, 5 and 4, 6. Previously conducted theoretical studies and obtained data made it possible to establish that the operating time of the traffic light authorization signal, at which there is no transport demand, is 157 minutes during the day in directions 3, 4, while it is equal to 150 minutes in directions 5, 6. Therefore, data on its road capacity during the operation of the traffic light were obtained in the course of experimental studies before and after improving the organization of traffic at this intersection. The total road capacity was 67,350 cars within 15 hours of operation before the installation of the "Calling Automobile System" system. However, this value increased by 9,082 cars after improving the organization of traffic at this intersection, as shown in figure 5.
Figure 5. Change in the road capacity when equipping the traffic light with the "Calling Automobile Device" system

As a result of the equipment of the traffic light facility with the "Calling Automobile Device" system increases in the road capacity in the main direction by an average of 13% and a decrease in the average time of vehicle delays.

The amount of fuel that is consumed by vehicles when idle for the red light was calculated on the basis of experimental and theoretical data on the average delay of vehicles and on fuel consumption by cars and trucks in idle mode during the year. The results of the calculation are presented in Table 1.

Table 1. The results of calculating the amount of fuel that cars consume when idle on the red light

| Indicator name                                                                 | Indicator value |
|--------------------------------------------------------------------------------|-----------------|
| The fuel consumption of cars and trucks during idling, l/h                     | 1.2             |
| The proportion of idle time of vehicles in the absence of the "Calling Automobile System" system (within 15 hours of traffic light) | 0.34            |
| The fuel that cars consume when idle for the red light, l/day (within 15 hours of traffic light) | 3.705           |

When the "Calling Automobile Device" system is put into operation, the road capacity is increased, the delay time of vehicles to the red light is reduced, the fuel consumption of cars is minimized by 3.705 liters (2.816 kg), and carbon dioxide emissions are reduced by 8.828 kg during the day. This causes an increase in the mobility of the population and an improvement in the environmental situation.

4. Discussions

Currently, the application of this system is possible at 7% of intersections in the urban environment, but new approaches to city planning and security on suburban routes lead to an increase in this value. The lack of transport demand from the secondary direction at the intersection, which is equipped with the "Calling vehicle system" system, increases the capacity of intersection in the main direction and reduces the time of vehicle delays, which causes an increase in population mobility and an improvement in the environmental situation. The cost of this system is low and amounts to 242,000 rubles. Its application is possible in remote areas, since it has a simple principle of operation
and complete autonomy. Currently, the "Calling Automobile Device" system works by directs reading of vehicles that have arrived at the detection zone. However, in the future, the authors plan to develop a new type of detection, which is due to the development of transport.

The increase in the share of electric vehicles, which is one of the directions of the transport development strategy, leads to new types of detection that allow reducing the time and error of its readout. Therefore, in the future, the authors plan to create a new type of system that connects with an electric vehicle and includes a red light in the main direction.

5. Conclusion
In the course of experimental studies, the authors identified characteristic intersections that must be equipped with the developed system: departures from adjacent territories, in particular hospitals, administrative buildings; crossing, which connect the major sports facilities, industrial enterprises with the city's road network. The obtained results confirm the necessity to create an industrial sample of the adaptive traffic management system, which was called the "Calling Automobile Device", and lead to the need to evaluate the effectiveness of its implementation in operation. It represents a video detector and a controller that, with the help of a given algorithm, controls the traffic signal regulation and allows to increase the intersections capacity with unstable transport demand by time and direction by 13%, and also to reduce carbon dioxide emissions by 8.828 kg / day, which contributes to the improvement of the ecological situation. Also, the need for further development of this system was identified with the aim of adapting it to work with electric vehicles.

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