Development of a method for evaluation of the efficiency of the coordinated type of management as referred to main streets

Sergei Dorokhin[1], *Valery* Ivannikov[1], *Dmitry* Likhachev[1], and *Alexander* Artemov[1*]

[1]Voronezh State University of Forestry and Technologies named after G.F. Morozov, 8, Timiryazeva str., 394087 Voronezh, Russia

Abstract. The use of coordinated management is a justified measure for the organization of traffic on regulated main streets, especially with high loads on the road network, in cases where the intensity of traffic flow is approaching the value of capacity. These "peak" loads have a negative impact on the characteristics of the traffic flow, but these loads are not always characteristic of controlled main streets, and the introduction of coordinated management with such types of loads – "not peak" should be justified and appropriate. The existing criteria for entering the coordination of the main street do not allow us to assess the feasibility of using this type of control with low loads on the street and road network. In order to assess the effectiveness of the use of coordinated management of the main street at low load levels, within the framework of this article, an analysis of existing methods for evaluating the effectiveness of the type of management in question was carried out, a full-scale study of the main street was conducted. Voronezh and the simulation of the site under consideration was carried out with and without coordination, the results were evaluated, conclusions were formulated and directions for further research were determined. Keywords: coordinated control, input conditions, delay, saturation degree.

1 Introduction

The use of automated traffic control systems (ATCS) of high levels of development (3rd and 4th generations) is one of the areas that contribute to improving the efficiency of urban transport routes [Ebben, M. (2004), Novikov, A. (2017), Novikov, A. (2019), Kerimov, M. (2020)]. This direction is quite relevant and, along with the high requirements that are currently imposed on the equipment that ensures the operation of such systems, they also impose them on calculation methods. In order to reflect the main methods for calculating the consistency of management of regulated areas, within the framework of this work, an analysis of their calculated parameters and procedures used to establish them was carried out.

Most cities of the Russian Federation have main transport routes that connect different areas. Traffic on these highways, in view of the presence of a certain number of objects of attraction (residential complexes, municipal facilities, shopping and entertainment areas, and others), is forcibly regulated using traffic lights. The most effective way to organize traffic

---

[*] Corresponding author: artenov_a_u@mail.ru

in such sections is the introduction of coordinated (coordinated) management, which reduces the amount of delay by ensuring the movement of vehicles along the main highway according to the principle "from green to green" ("green wave") with the obligatory fulfillment of certain conditions (Fig. 1).

In the conditions of oversaturated road transport, typical for modern cities, the introduction of coordinated management is an event that helps to improve the situation in traffic, but due to the fact that the load on the road network is quite high, the intensity in conflicting directions with the main street is often also high. In addition, situations are quite often observed when, in unsaturated conditions, the introduction of coordination contributes to a deliberate excess of the speed of movement in order to pass the main street without deliberate stops.
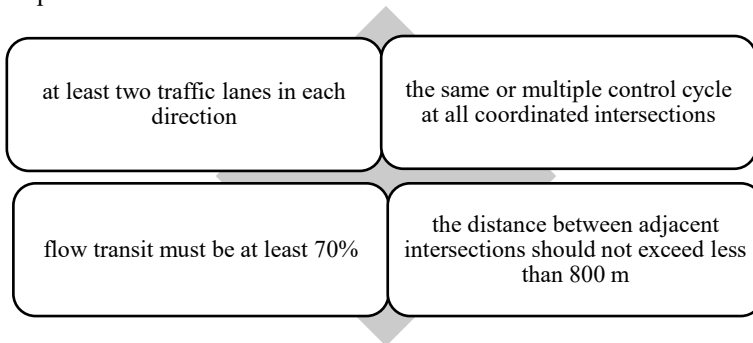

Fig. 1. Conditions for ensuring coordinated management.

In these cases, the introduction of coordinated control should be justified and expedient in terms of changing the main characteristics of the traffic flow. In order to determine the feasibility of applying coordinated management on the example of the main street in Voronezh, within the framework of the article, a study was carried out to assess the effectiveness of introducing the type of management under consideration.

2 Materials and methods

In foreign practice, to assess the effectiveness of the application of coordinated control, it is proposed to use a specialized coordination factor (coordination factor - coordination factor) (CF), which, according to a certain ratio of intensity to throughput, determines the feasibility of introducing coordination [Pilgeikina, I. (2017), Pilgeikina, I. (2020)]:

$$CF = 100 - \frac{AT}{SS} \qquad (1)$$

where AT (Average Traffic) - is the average traffic intensity for the regulation cycle, units/cycle; SS (Storage Space) - is the capacity of the section under consideration unit/cycle.

In this case, the components required to calculate the coefficient (1) are calculated using the formulas:

$$AT = \frac{q \cdot C}{3600} \qquad (2)$$

where q - is traffic intensity, units/h; C - is the set duration of the regulation cycle, s.

$$SS = \frac{n \cdot LD}{VL} \qquad (3)$$

where n - is the number of traffic lanes, LD - is the length of the connection between sections, m; VL - is the average length of cars.

As a result of the calculation, interpreting the data with the established ranges (Table 1), it is possible to determine the feasibility of introducing coordination in the areas under consideration.

Table 1. Interpretation of the ranges of values of the coordination coefficient.

Range CF	Action name
CF >80	Expedient input of coordination
20 < CF < 80	Possible input of coordination
CF < 20	Inappropriate input of coordination

When determining the feasibility of commissioning, using the coordination coefficient (1) (Table 1) and observing the established conditions (Fig. 1), the necessary control parameters are calculated in the coordinated area.

In domestic practice, it is possible to evaluate the effectiveness of introducing coordinated control by calculating the delay value, which in this case is determined using the formula:

$$d = d_1(k_{pr}) + d_2 \qquad (4)$$

where d_1 - is the standard delay, assuming the same repeated arrival of vehicles at the intersection, s/prev.un.; k_{pr} is the progression coefficient of the standard delay, taking into account the progression of regulation; d_2 - additional delay, taking into account the randomness of the arrival of vehicles, s/adv.un.

The progression coefficient is determined using the formula:

$$k_{pr} = \frac{(1-P)f_{Tn}}{1-\left(\frac{g}{C}\right)} \qquad (5)$$

where P - is the share of vehicles that arrived during the green signal, units/cycle; g/C - is the proportion of the green signal in the cycle; f_{Tn} - is a coefficient that takes into account the type of arrival of vehicles at the regulated intersection.

The coefficient taking into account the type of arrival, in this case depends on the degree of saturation and is in the limit of 0 ... 1 and crew time, depending on the established data (Table 2), the value of the considered coefficient is selected.

Table 2. The value of the arrival coefficient f_{Tn}.

Crew time. s	Load level (saturation factor) X					
	≤0.5	0.6	0.7	0.8	0.9	≥1.0
≤2.0	0.04	0.13	0.22	0.32	0.41	0.50
2.5	0.08	0.16	0.25	0.33	0.42	0.50
3.0	0.11	0.19	0.27	0.34	0.42	0.50
3.5	0.13	0.20	0.28	0.35	0.43	0.50
4.0	0.15	0.22	0.29	0.36	0.43	0.50
4.5	0.19	0.25	0.31	0.38	0.44	0.50
5.0	0.23	0.28	0.34	0.39	0.45	0.50

The standard delay d_1 in this case, the case of coordinated control, is determined using the formula:

$$d_1 = \frac{0{,}5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]} \qquad (6)$$

where C - is the length of the control cycle, s; g is the duration of the green signal, s; X - is the load level for the considered group of traffic lanes.

Additional d_2, calculated using the formula:

$$d_2 = 900T \left[(X - 1) + \sqrt{(X - 1)^2 + \frac{8k_{pr}IX}{cT}} \right] \qquad (7)$$

where c_i - is the capacity of a group of traffic lanes, lead units/h; T - is the length of the analyzed period, h; I - coefficient taking into account the remoteness of the previous section (in the direction of movement) of the regulated intersection from the one under consideration; X - loading level.

The value of the coefficient I, is determined depending on the load level at the previous intersection using the data presented in Table 3.

Table 3. Coefficient taking into account the remoteness of the previous section.

Load level at the previous intersection X_{pr}	0.40	0.50	0.60	0.70	0.80	0.90	≥1.0
I	0.922	0.858	0.769	0.650	0.500	0.314	0.090

As a result of the analysis of the presented formulas, it can be said that, basically, the assessment of the effectiveness of coordinated management on the main street allows us to evaluate the values of certain coefficients that are characteristic only for the type of management under consideration.

To perform the procedure for evaluating the effectiveness of introducing coordinated control, within the framework of this study, the calculation of the efficiency was performed by the value of the delay set for coordinated control using the presented formulas and certain coefficients and without introducing coordinated control without taking into account the coefficients.

3 Experiment

The intersections of st. Brusilova, st. Dimitrov, st. Minskskaya with Leninsky Prospekt (Fig. 2). In this section, during the analysis of the composition, by analogy with the composition of large cities [Cureton, P. (2020), Dhingra, K. (2020)], the largest flow of cars is observed.
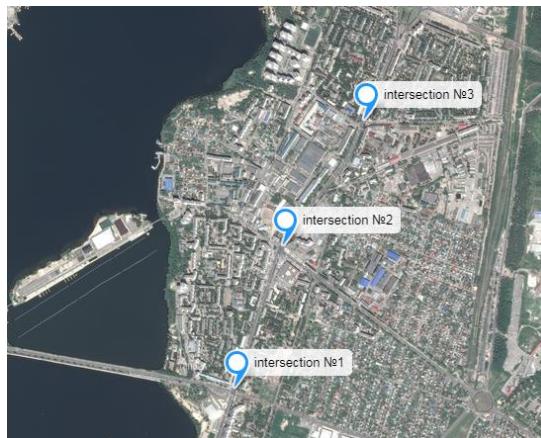

Fig. 2. Designation of the surveyed areas along Leninskiy Prospekt.

As a result of the calculations presented in Table 4, it was found that with the introduction of coordinated regulation on the prospectus under consideration, it is possible to reduce the delay time by an average of 21%, provided that the degree of saturation of the sections under consideration is 0.9.

Table 4. The results of calculating the amount of delay when entering and without entering coordinated control.

№	Name of intersections	delay value without input of coordinated control. (t. s)	delay value when entering coordinated control. (t. s)	Reducing the average delay. s	Changing the delay value. %
1	Leninsky Prospekt - st. Brusilova	63.28	52.35	10.93	-17%
2	Leninsky Prospekt - st. Dimitrova	225.27	185.39	39.88	-18%
3	Leninsky Prospekt - st. Minsk	373.38	261.19	112.19	-30%

As a result of the simulation, the effectiveness of introducing coordinated control was estimated depending on the change in the degree of saturation [Novikov, A. (2020)] in the areas under consideration (Fig. 3 - Fig. 5).

Despite the different values of the intensity in the areas under consideration, the nature of the change in the graphs is identical, so at the intersection of Leninsky Prospekt - st. Brusilova (Fig. 3) at which the intensity value was minimal in comparison with other intersections, the minimum delay value was 2 s. At a busier intersection - Leninsky Prospekt - st. Dimitrov (Fig. 4), the minimum value of the delay was 7 s with input of coordination and 9 s without input. The final intersection - Leninsky Prospekt - st. Minsky (Fig. 5) showed a minimum value of 10 s with the input of coordination and 14 s without input, taking into account the same motion conditions and the degree of saturation of 0.5, which is clearly reflected in the histograms (Fig. 3 - Fig. 5), on which the results are indicated in blue without the use of coordinated control, and in red, with its use.
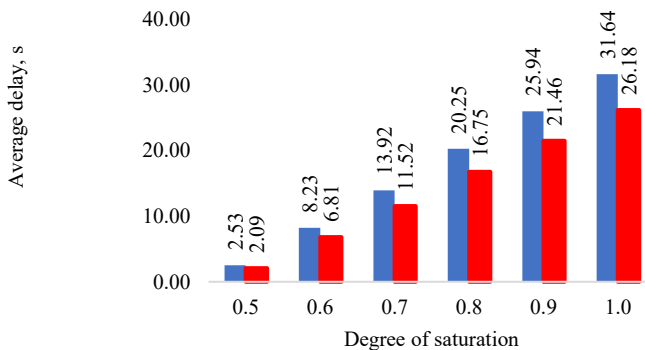

Fig. 3. Graph of the change in the magnitude of the delay when the degree of saturation changes at the section - Leninskiy Prospekt - st. Brusilova.
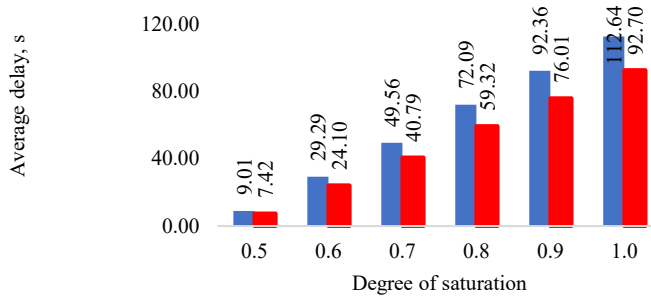
Fig. 4. Graph of the change in the magnitude of the delay when the degree of saturation changes at the section - Leninskiy Prospekt - st. Dimitrova.
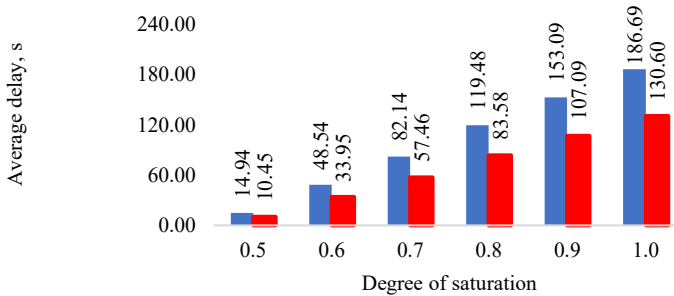

Fig. 5. Graph of the change in the magnitude of the delay when the degree of saturation changes at the section - Leninskiy Prospekt - st. Minsk.

It has been established that the introduction of coordinated regulation in the considered sections provides the greatest efficiency with a saturation degree of 0.7, in this case the difference between the delay values will be more than 30%.

The degree of saturation in the case of the introduction of coordinated control refers to the transport characteristics, but the geometric component is also important. According to the requirements for the introduction of coordinated control (Fig. 1), the distance between intersections should be at least 800 m, we will evaluate the effectiveness of this indicator, when changing the distances between neighboring ones, which becomes possible when performing the simulation procedure.

As a result of changing the distance between adjacent intersections and performing the simulation procedure, it was found that with an increase in the distance by 100 m, the delay increases by an average of 5% with the introduction of coordinated control (black color of the histograms) and without its use (red color of the histograms) (Fig. 6 - Fig. 8).
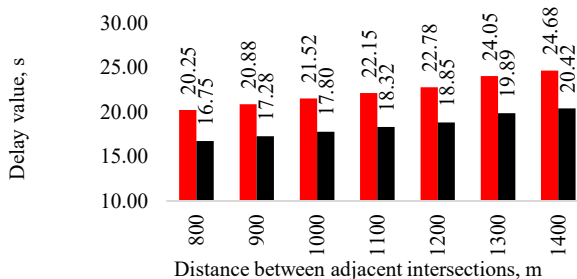

Fig. 6. Graph of the change in the delay value when the distance between adjacent intersections changes on the site - Leninskiy Prospekt - st. Brusilova.
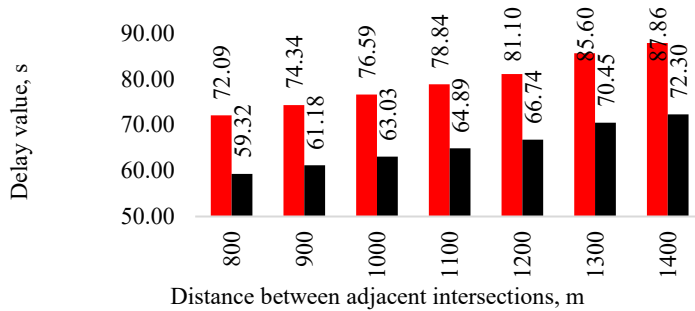
Fig. 7. Graph of the change in the delay value when the distance between adjacent intersections changes on the site - Leninskiy Prospekt - st. Dimitrova.
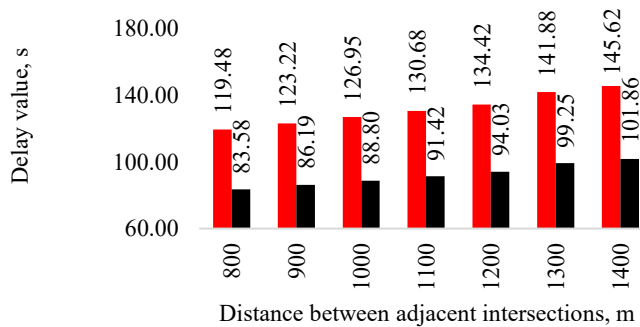

Fig. 8. Graph of the change in the amount of delay at the section - Leninsky Prospekt - st. Minsk.

The nature of the change in the graphs and the performed calculations make it possible to judge that when the distance between intersections changes, the coordination of traffic light regulation does not have a significant effect under similar conditions without coordinated control.

4 Conclusions

As a result of the calculations performed and the analysis of the data obtained, the conditions were determined under which the introduction of coordinated control would be considered justified and effective. According to the performed calculations, it was determined that when a coordinated control is introduced, in addition to the transit capacity of the flow of 70%, an important value is the degree of saturation, which allows one to judge the degree of loading of the entire regulated section. By changing the value in steps of 0.1, a saturation degree of 0.7 was set, corresponding to comfort level C, for which the difference between the delay value was more than 30%.

When evaluating the efficiency by distance, the same difference was established between the value of the delay when introducing coordinating regulation and without it, with a change in the distance between adjacent intersections with a step of 100 m.

The established dependences make it possible to evaluate the effectiveness of introducing coordinated control by changing the delay value depending on the transport characteristic [Dorokhin, S. (2018), Shevtsova, A. (2021), Glagolev, S. (2018), Zelikov, V. (2019), Dorokhin, S. (2022)], determined in the framework of the study by the degree of saturation and the geometric characteristic - the distance between the controlled coordinated sections.

The main direction of further research will be the analysis of the speed of movement and the establishment of patterns of change in the parameters under consideration from the established control modes.

Reference

1. S. Borah, H. Dihingia, J.K. Laphong, International Journal of Innovative Science and Research Technology, 168-169 (2019)

2. P. Cureton, Drone Futures, 148-181 (2020)

3. M. Ebben, M. Van Der Heijden, D.J. Van Der Zee, Transportation Research Part B: Methodological **38(5)**, 441-458 (2004) DOI 10.1016/S0191-2615(03)00075-4

4. S. Glagolev, A. Shevtsova, S. Shekhovtsova, Transportation Research Procedia **36**, 193-198 (2018) DOI 10.1016/j.trpro.2018.12.063

5. K. Dhingra, International Journal of Engineering and Technical Research, 1263-1266 (2020)

6. S.V. Dorokhin, D.V. Likhachev, A.Yu. Artemov, Lecture Notes in Networks and Systems **402 LNNS**, 1586-1594 (2022) DOI 10.1007/978-3-030-96380-4_175

7. S.V. Dorokhin, V.A. Zelikov, Y.V. Strukov, Journal of Physics: Conference Series, 032128 (2018) DOI 10.1088/1742-6596/1015/3/032128

8. M. Kerimov, A. Marusin, I. Danilov, Transportation Research Procedia **14**, 253-261 (2020) DOI 10.1016/j.trpro.2020.10.031.

9. A. Novikov, S. Glagolev, I. Novikov, A. Shevtsova, IOP Conference Series: Materials Science and Engineering **632**, 012052 (2019) DOI 10.1088/1757-899X/632/1/012052

10. A. Novikov, I. Novikov, A. Katunin, A. Shevtsova, Transportation Research Procedia **20**, 455-462 (2017)

11. A. Novikov, I. Novikov, A. Shevtsova, Transportation Research Procedia **36**, 548-555 (2018) DOI 10.1016/j.trpro.2018.12.154.

12. I.A. Pilgeikina, A.A. Vlasov, Education and science in the elite world. Innovation **2(9)**, 202-208 (2017)

13. I.A. Pilgeikina, World of Transport and Technological Machines **1(68)**, 59-64 (2020)

14. A. Shevtsova, A. Novikov, Journal of Applied Engineering Science **19(1)**, 30-36 (2021) DOI 10.5937/jaes0-26642

15. V.A. Zelikov, G.A. Denisov, S.V. Dorokhin, Studies in Computational Intelligence **826**, 1081-1088 (2019) DOI 10.1007/978-3-030-13397-9_111