Development of an approach to the selection of the necessary method of arrangement of the left turn in the area of controlled intersection

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Abstract. In this article the analysis of the main ways of the organization of the left turn in a zone of the regulated intersection with use of foreign and domestic scientific sources is carried out. In the analysis the authors determined that today in the choice of the necessary way of organizing the left turn option uses a minimal set of data, namely, intensity of traffic, causing a traffic controlled junctions may not be effective. Studies of changes in the main characteristics of the traffic flow as a result of conflict analysis "left turn-direct conflicting flow" allowed the authors to develop a new approach to the selection of the necessary method of arrangement of the left turn, taking into account changes in the main characteristics of the traffic flow – delay, speed and queue length. The experiment showed the feasibility of using the proposed approach.

1. Introduction

Daily due to the rapid growth of level of automobilization [1-3] in the world and on the roads of the Russian Federation there are many negative factors, such as the loss of time, the formation of queues and congestion, unnecessary fuel consumption, wear of components, wear of road surface, environmental degradation, and another important factor is the occurrence of accidents, injury and death, leading to substantial losses for the state. These problems are particularly acute in the regulated areas, in this regard, it is necessary to develop a new approach to the selection of the optimal control scheme, namely the introduction of an additional phase of regulation.

When introducing an additional control phase on regulated areas, it is necessary to analyze conflicting directions and consider the traffic process using additional characteristics of the traffic flow in order to determine the rational use of the additional time of the traffic light cycle. In this regard, the main objective of the study – the rationale for entering the additional phase regulation and development approach to the choice of rational schemes of organization of traffic left turn, taking into account changes of characteristics of the traffic flow.

2. Analysis of existing approaches to the organization of the left turn

An analysis of the world experience in introducing an additional left-turn band was carried out using many sources [4–8], including research reports, state and federal design guidelines, and reference books.
Based on the analysis, the existing foreign approaches to the specialization of the left-turning lane are divided depending on the parameters and traffic conditions:

1. Approaches based on the accident rate of the regulated area; these approaches, despite the use of the characteristics of the traffic flow, are mainly based on the number of road accidents.

According to the approaches assigned to the first group, there are basic parameters necessary when taking into account the specialization of the left-turning band:

- Incoming intensity ($N_{inc}$) is the total hourly peak traffic on the main road, cars move in the same direction together with the left-hand flow.
- Left-turn flow intensity ($N_{left}$) is the part of the incoming intensity that turns left at the intersection.
- Left rotation percentage ($\%_{Left}$) – percentage of incoming intensity that turns left:
  \[
  \%_{Left} = \left[ \frac{N_{left}}{N_{inc}} \right] \times 100.
  \]
- Forward flow rate ($N_{dir}$) is the part of the incoming intensity that goes directly through the intersection:
  \[
  N_{dir} = N_{left} + N_{inc}.
  \]
- Counter intensity ($N_{count}$) – the total peak hourly intensity of vehicles moving towards the incoming intensity.

Despite the basic parameters of the traffic flow, the fundamental factor will be the number of accidents at the intersection associated with the left turn, a total of four or more such accidents in 12 months or six or more in 24 months will be the basis for the specialization of the left turn.

2. Approaches based on the analysis of the main characteristics of the traffic flow.

The scientists of Park, B. and Lee, J. [6] have improved the main parameters used in the specialization of the left-turning band: 1. a critical interval of 5.5 seconds (instead of 5.0 seconds); 2. time to turn left 4.3 s (instead of 3.0 s); 3. time to clear the strip 3.2 s (instead of 1.9 s).

In addition, depending on the speed of movement and the volume of the left turn from the direct flow, critical values were obtained for entering a specialized band [8].

According to studies of the approaches assigned to the second group, the rationale for introducing an additional regulatory phase is to compare the intensity of the conflicting flow and the percentage of left rotation.

In domestic practice, to determine the algorithm for entering the additional regulation phase, it is initially necessary to consider the structure of the cycle and the sequence of calculation of its main elements. In more detail, the domestic experience was determined by the authors in a scientific study [9,10], however, to date, the use of an additional left-hand lane is associated with the introduction of a separate third phase in the traffic control cycle if the intensity of the left turning flow is more than 120 aut./h [11]. The main calculation will depend on the geometry of the regulated section in the area of calculating the saturation flux of such a band and, accordingly, the duration of the regulation phase [12].

As a result of using a minimal data set, namely, knowing only the intensity of the left turn, the organization of traffic at an adjustable intersection is possibly inefficient. In order to expand the field of knowledge in this matter, the necessary measure will be the development of a sound scientific approach using previously unused characteristics of the transport stream to develop an approach to the introduction of a specialized left-handed lane and regulation phase. This event will further improve the efficiency of regulated intersections. During the study of scientific literature, the main approaches to the introduction of an additional left-handed control phase were established. It was determined that when entering the extended regulation phase, the main parameters of the traffic flow, such as the length of the queue, the intensity of the conflicting flow, speed and delays of the vehicles, are not taken into account. In this regard, the necessary measure is the development of a scientifically based approach to the introduction of a specialized regulation phase at controlled intersections, taking into account the main characteristics of the traffic flow.

3. Crossroads research

An analysis of the main regulated intersections in Voronezh showed that today there are several ways
to organize left-hand traffic (these methods are typical for many cities of the Russian Federation), which are as follows:

1. Organization of the movement of the left turn, together with the direct movement from one lane in one phase of regulation («method 1»).
2. Organization of the movement of the left turn from a specialized lane in one phase of regulation («method 2»).
3. Organization of a left turn from a specialized lane together with the use of an «elongated regulation phase» («method 3»).
4. Organization of a left turn from a specialized lane in a specialized phase of regulation («method 4»).

The presented methods of organizing the movement of the left turn are quite different and require the development of a reasonable description of the input of each of them. In the presented scientific sources there are no strictly regulated requirements for the selection of each of them.

A study of the main regulated intersections in Voronezh showed that with various ways of organizing traffic, the main parameters of the traffic flow, namely, speed, queue length and vehicle delays, change. In order to develop a reasonable method for choosing the necessary organization of the left turn, it is necessary to assess the change in the main parameters of the traffic flow.

To evaluate changes in these parameters (speed, delay, queue length), an analysis of their change is necessary for various combinations of left-turning N₁ traffic flow and oncoming conflicting N₂. During model experiments, changes in speed, delays and maximum queue length for a conflicting stream were determined (Fig. 1–3).

![Figure 1](image)

**Figure 1.** Change in delays with the ratio of intensities N₁ to N₂

The minimum value for vehicle delays is 2.77 s with a ratio of N₁ = 50 units/h to N₂ = 250 units/h, the maximum value is 2644.97 s, with a ratio of N₁ = 50 units/h to N₂ = 3000 units/h, and the average delay is 918.19 s. In most ratios of intensities N₁ and N₂, delays in the model are directly dependent and have a pronounced upward trend with downward correction and a local maximum of delays of 756.98 s with a ratio of N₁ = 1000 units/h to N₂ = 750 units/h.

The minimum value of the queue length of vehicles is 1 aut. with a ratio of N₁ = 50 units/h to N₂ = 250 units/h, the maximum value is 1087 aut. with a ratio of N₁ = 1000 units/h to N₂ = 3000 units/h, and the average value of the length of the vehicle queue is 918.19 aut. In most ratios of intensities N₁ and N₂, the queue length in the model is directly dependent and has a pronounced upward trend.
The minimum vehicle speed is 4.75 km/h with a ratio of $N_1 = 750$ units/h to $N_2 = 2750$ units/h, the maximum value is 52.55 km/h with a ratio of $N_1 = 1000$ units/h to $N_2 = 3000$ units/h, and the average vehicle speed is $-23.35$ km/h. In most ratios of intensities $N_1$ and $N_2$, speed in the model is inversely related and have a pronounced downward trend with upward correction and a local minimum of $26.7$ km/h with a ratio of $N_1 = 950$ units/h to $N_2 = 500$ units/h.

As a result of determining the main parameters of the traffic flow with a combination of the intensities of the left-hand flow and the direct conflicting flow for one and two lanes, it became possible to determine the possible ranges of changes in speed, delay and queue length, which are fundamental parameters in determining the necessary way of organizing the movement of the left-turn flow.

4. Approach to the organization of the left turn in the area of the regulated intersection

In order to determine the parameter values for each possible combination, the authors proposed to switch...
to a system of ratio coefficients, each of which will be interpreted by certain values of the considered parameters (queue length, speed, delay). The obtained values of the coefficients are presented in table 1.

\[ K_i = \frac{N_i}{N_j} = n = \{t_n = x_n; l_n = y_n; v_n = z_n\} \]  

(3)

where \( K_i \) – the coefficient of the ratio of \( N_i \) to \( N_j \), \( N_j \) – intensity of movement of the left turn, units/h; \( N_j \) – the intensity of the movement of a direct conflicting stream moving in one lane, units/h; \( n \) – the value of the ratio coefficient (0.02 ... 4.0); \( t_n \) – delay time of the vehicle, s.; \( x_n \) – the value of the delay time, for a given ratio of intensities, \( s.\); \( l_n \) – vehicle queue length, units; \( y_n \) – is the value of the queue length, for a given intensity ratio, units; \( v_n \) – speed, km/h; \( z_n \) – the value of the speed of movement, for a given ratio of intensity, km/h.

Table 1. Value of the ratio \( N_1 \) and \( N_2 \)

| \( N_1 \) | 50  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1000 |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 250      | 0.20| 0.40| 0.60| 0.80| 1.00| 1.20| 1.40| 1.60| 1.80| 2.00| 2.20| 2.40| 2.60| 2.80| 3.00| 3.20| 3.40| 3.60| 3.80| 4.00|
| 500      | 0.10| 0.20| 0.30| 0.40| 0.50| 0.60| 0.70| 0.80| 0.90| 1.00| 1.10| 1.20| 1.30| 1.40| 1.50| 1.60| 1.70| 1.80| 1.90| 2.00|
| 750      | 0.07| 0.13| 0.20| 0.27| 0.33| 0.40| 0.47| 0.53| 0.60| 0.67| 0.73| 0.80| 0.87| 0.93| 1.00| 1.07| 1.13| 1.20| 1.27| 1.33|
| 1000     | 0.05| 0.10| 0.15| 0.20| 0.25| 0.30| 0.35| 0.40| 0.45| 0.50| 0.55| 0.60| 0.65| 0.70| 0.75| 0.80| 0.85| 0.90| 0.95| 1.00|
| 1250     | 0.04| 0.08| 0.12| 0.16| 0.20| 0.24| 0.28| 0.32| 0.36| 0.40| 0.44| 0.48| 0.52| 0.56| 0.60| 0.64| 0.68| 0.72| 0.76| 0.80|
| 1500     | 0.03| 0.07| 0.10| 0.13| 0.17| 0.20| 0.23| 0.27| 0.30| 0.33| 0.37| 0.40| 0.43| 0.47| 0.50| 0.53| 0.57| 0.60| 0.63| 0.67|
| 1750     | 0.03| 0.06| 0.09| 0.11| 0.14| 0.17| 0.20| 0.23| 0.26| 0.29| 0.31| 0.34| 0.37| 0.40| 0.43| 0.46| 0.49| 0.51| 0.54| 0.57|
| 2000     | 0.03| 0.05| 0.08| 0.10| 0.13| 0.15| 0.18| 0.20| 0.23| 0.25| 0.28| 0.30| 0.33| 0.35| 0.38| 0.40| 0.43| 0.45| 0.48| 0.50|
| 2250     | 0.02| 0.04| 0.07| 0.09| 0.11| 0.13| 0.16| 0.18| 0.20| 0.22| 0.24| 0.27| 0.29| 0.31| 0.33| 0.36| 0.38| 0.40| 0.42| 0.44|
| 2500     | 0.02| 0.04| 0.06| 0.08| 0.10| 0.12| 0.14| 0.16| 0.18| 0.20| 0.22| 0.24| 0.26| 0.28| 0.30| 0.32| 0.34| 0.36| 0.38| 0.40|
| 2750     | 0.02| 0.04| 0.05| 0.07| 0.09| 0.11| 0.13| 0.15| 0.16| 0.18| 0.20| 0.22| 0.24| 0.25| 0.27| 0.29| 0.31| 0.33| 0.35| 0.36|
| 3000     | 0.02| 0.03| 0.05| 0.07| 0.08| 0.10| 0.12| 0.13| 0.15| 0.17| 0.18| 0.20| 0.22| 0.23| 0.25| 0.27| 0.28| 0.30| 0.32| 0.33|

To determine the necessary way of organizing traffic at a regulated intersection from the four previously considered it is necessary to interpret the obtained values of vehicle delays with the existing service levels of the regulated intersection.

As a result of the mathematical analysis of the data, the main limits were determined by combining the critical intensities for the left turn and the direct conflicting flow, characterized by the ratio coefficient. Each coefficient obtained can be described by the corresponding value of the characteristics of the traffic flow (queue length, delay and speed). The study of changes in these indicators when using traffic light control and comparing the obtained data with the value of the delay characteristic for the corresponding level of service, during the course of the study made it possible to determine the corresponding areas characterized by the initial parameters – the intensity – and determine the corresponding areas for each level. For each service level, a mathematical model and its main parameters are determined by the result of mathematical analysis.

Based on the analysis of changes in the main values of the traffic flow during the study of the «left turn-direct conflicting flow» conflict, such as speed, queue length and delay value, it is proposed to use the ratio coefficient, which will serve as the main value when choosing the necessary method of organizing the movement of the left turn at an adjustable intersection. Each value of the coefficient will be characterized by the corresponding value of the main values that will be observed at the intersection. By connecting the obtained coefficient value with the value of the delay value of cars, it is possible to determine the level of service at the intersection and thereby determine the necessary way of organizing traffic, which is shown in detail in table 2.

As a result of the mathematical analysis of the conflict in question, an algorithm was developed for choosing the necessary method of organizing movement in an adjustable area.
Table 2. Methods of organizing the movement of the left-hand flow by service levels

| Type   | Thresholds, units/h | Coefficient | Delays, s. | Queue length, aut | Speed, km/h | Service level |
|--------|---------------------|-------------|------------|-------------------|-------------|---------------|
|        |                     |             |            |                   |             |               |
| 1)     | N₂ = 500, N₁ = 50–400; | 1) 0,1–0,8; | 1) 2,69–9,3; | 1) 0,18–0,82; | 1) 52,7–48,7; |               |
| 2)     | N₂ = 1000, N₁ = 50–200; | 2) 0,05–0,2; | 2) 4,14–9,45; | 2) 0,85–0,9; | 2) 51,93–49,57; |               |
| 3)     | N₂ = 1500, N₁ = 50–100; | 3) 0,03–0,07; | 3) 5,92–7,39; | 3) 1,42–1,58; | 3) 50,81–50,17; |               |
| 4)     | N₂ = 2000, N₁ = 50; | 4) 0,03 | 4) 8,73 | 4) 2,33 | 4) 49,06 |               |
|        |                     |             |            |                   |             |               |
| 1)     | N₂ = 500, N₁ = 450–700; | 1) 0,9–1,4; | 1) 11,46–19,16; | 1) 0,97–1,37; | 1) 47,75–44,72; | A (≤ 10 s.) |
| 2)     | N₂ = 1000, N₁ = 250–300; | 2) 0,25–0,3; | 2) 10,3–16,29; | 2) 0,97–1,12; | 2) 49,07–47,02; |               |
| 3)     | N₂ = 1500, N₁ = 150–250; | 3) 0,1–0,17; | 3) 11,52–19,28; | 3) 1,5–1,6; | 3) 48,5–46,42; |               |
| 4)     | N₂ = 2000, N₁ = 100; | 4) 0,05; | 4) 10,67; | 4) 2,58; | 4) 48,48; |               |
| 5)     | N₂ = 2500, N₁ = 50; | 5) 0,02 | 5) 14,56 | 5) 3,93 | 5) 46,15 |               |
|        |                     |             |            |                   |             |               |
| 1)     | N₂ = 750–800; N₁ = 850–900; | 1) 1,5–1,6; | 1) 24,4–29,28; | 1) 1,8–2,05; | 1) 42,95–41,62; |               |
| 2)     | N₂ = 1000, N₁ = 350–500; | 2) 0,35–0,5; | 2) 21,18–30,69; | 2) 1,1–1,35; | 2) 45,96–43,62; |               |
| 3)     | N₂ = 2000, N₁ = 150; | 3) 0,08 | 3) 20,97 | 3) 2,48 | 3) 45,73 |               |
| 4)     | N₂ = 500, N₁ = 100; | 1) 1,7–1,8; | 1) 38,53–38,93; | 1) 1,9–2,18; | 1) 39,91–39,47; | D (35–55 s.) |
| 5)     | N₂ = 2500, N₁ = 50; | 2) 0,04; | 2) 41,39; | 2) 5,37; | 2) 40,53; | E (55–80 s.) |
| 6)     | N₂ = 3000, N₁ = 50; | 3) 0,02 | 3) 51,21 | 3) 11,38 | 3) 37,24 | F (>80 s.) |

5. Experiment
To assess the effectiveness of the proposed approach, a model experiment was performed at one of the regulated intersections of Voronezh using the Aimsun simulation product (fig. 4, 5).

Figure 4. Satellite image of the object of study  Figure 5. Model of the object of study
The organization of the left turn at the object of study occurs according to «method 2». As a result of the simulation, it was found that the average value of the delays is 160.19 s, and the average value of the vehicle speed is 25.54 km/h.

Field studies allowed us to determine the intensity of the left turn \( N_1 = 87 \) units/h, the intensity of the oncoming flow \( N_2 = 800 \) units/h.

Using the approach proposed for work (table 2), it follows that for these combinations of intensity, which are included in the threshold values of service level A, it is advisable to use the «method 1» of organizing the left turn (the movement of the left-turn flow together with the direct flow from one lane to single phase).

As a result of the simulation, after implementing this method for these intensities, the average value of the delays decreased by 19 %, and the average value of the speed increased by 16 % (table 3).

**Table 3.** Indicators of traffic flow before and after the reorganization of the existing traffic management scheme

| Traffic characteristic | Indicators of traffic flow with the existing traffic management scheme | Indicators of traffic flow after the reorganization of the existing traffic management scheme |
|------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| Delays, s.             | 160.19                                                         | 129.84                                                         |
| Speed, km/h            | 25.54                                                         | 29.81                                                          |

It is established that when introducing a new method of organizing a left turn, the situation in the analyzed object of study improves.

6. Conclusion

As a result of the study, it was found that to date, schemes for organizing the movement of the left turn are not effective, in connection with which congestion situations are observed at intersections and many transport characteristics are of increased and reduced value. In order to improve the transport situation and the smooth distribution of the traffic flow, namely, the harmonious movement of vehicles, a new approach was proposed to equip the left turn in the area of the regulated intersection. The performed model experiment showed the feasibility and effectiveness of using the approach proposed to develop based on the study of the «left turn – direct conflicting flow» conflict and determining the values of the main characteristics of the traffic flow – speed, queue length, and delays. As a result of testing the developed approach in the studied section of the road network, it was possible to reduce the average delay by 19 % and increase the speed by 16 %.

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