Development of an algorithm for choosing the specialization of the left-turn lane in the zone of a controlled intersection

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Abstract. The article is devoted to the methods of organization of left-turn traffic in the area of regulated intersections. As a result of the study of the world experience of arrangement of left-turn traffic at controlled intersections, the authors found that today there is no reasonable approach to the specialization of the strip, based on the study of the main characteristics of the traffic flow. The authors have developed an algorithm based on previously unused characteristics, which allows, depending on the ratio of the intensity of the conflict "direct conflicting and left-turn flow" to determine the necessary way of organizing the movement. As a result of testing the developed algorithm, the efficiency of developed algorithm of choice of specialization to allow left-turn lanes in the area controlled intersection.

1 Introduction

Today, emergency situations are often observed at regulated intersections. This is often due to the high level of motorization, which is now significantly high and this is typical for many countries, including the Russian Federation. In most cases, accidents at controlled intersections occur due to inefficient organization scheme, namely in connection with the inconsistent distribution of time permitting and prohibiting control cycles. Particular attention in this matter should be paid to the methods of entering an additional left-turn section. In this regard, a detailed review of existing approaches to the allocation of a specialized left-turn lane for the selected phase of regulation (additional section of the left turn), using foreign and domestic scientific sources [1-7].

2 Study of left-turn lane specialization methods

According to the analysis of foreign literature [1-4], today there are several methods to determine the need for an additional left-turn section, they can be divided into the following approaches:

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1. Approaches based on the risk of road accidents [1,2]. According to this approach, specialized left turn phases should be introduced if more than four left turn accidents have occurred at an intersection (a section of a dense network) in the past 12 months. The irrationality of using this approach lies in the fact that the main characteristics of the traffic flow, which are defined in the approaches belonging to the second group, are not considered.

2. Approaches based on the analysis of the main characteristics of the traffic flow. These approaches are based on a comparison of incoming and oncoming traffic, average speed and percentage of left turn (table 1)

| Operating speed (mph) | Counter intensity (vehicles/h) | Part of the intensity (vehicles/h) |
|-----------------------|-------------------------------|-----------------------------------|
|                       |                              | 5% turn to the left | 10% turn to the left | 20% turn to the left | 30% turn to the left |
| 40                    | 800                           | 330                  | 240                  | 180                  | 160                  |
|                       | 600                           | 410                  | 305                  | 225                  | 200                  |
|                       | 400                           | 510                  | 380                  | 275                  | 245                  |
|                       | 200                           | 640                  | 470                  | 350                  | 305                  |
|                       | 100                           | 720                  | 515                  | 390                  | 340                  |
| 50                    | 800                           | 280                  | 210                  | 165                  | 135                  |
|                       | 600                           | 350                  | 260                  | 195                  | 170                  |
|                       | 400                           | 430                  | 320                  | 240                  | 210                  |
|                       | 200                           | 550                  | 400                  | 300                  | 270                  |
|                       | 100                           | 615                  | 445                  | 335                  | 295                  |
| 60                    | 800                           | 230                  | 170                  | 125                  | 115                  |
|                       | 600                           | 290                  | 210                  | 160                  | 140                  |
|                       | 400                           | 365                  | 270                  | 200                  | 175                  |
|                       | 200                           | 450                  | 330                  | 250                  | 215                  |
|                       | 100                           | 505                  | 370                  | 275                  | 240                  |

In the future, the approaches related to the second group were improved [4], in connection with the change in the technical parameters of cars, the recommendations for the percentage ratio of the intensity of the left turn were changed. As a result of the received information, it is established that in foreign sources there are a number of approaches that must be applied when choosing a rational scheme of traffic organization in the regulated area, in particular when allocating a specialized phase of the left turn.

The analysis of scientific domestic sources [5-7] showed that the calculation of the traffic light cycle, namely the input of the left-turn separate direction (left-turn section) at the intersection is carried out in accordance with the regulations. According to the requirements, the capacity of the left turn depends on the intensity of the main flow. Skipping the left turning flow (number of cars) is proportional to the intensity of the oncoming direction. Allow left-turn stream is recommended to clean the counter percolation through the direct flow, which depends on the duration of the basic cycles, if its intensity does not exceed 120 vehicles/h. If the intensity of the left turning flow more than 135 unit/h (120 vehicles/h), it is recommended to enter the third phase or use other methods of traffic organization for the assignment of a left turn from the zone of intersection of roads.

In cases of partial conflict miss traffic on «seepage» through the pedestrian flow is possible when the intensity of the traffic flow not exceeding 120 vehicles/h, the intensity of pedestrian flow 900 pers./h. to analyze the basic parameters of traffic flow and development of a specialized approach to the choice of rational schemes of organization of traffic on a regulated intersection, Voronezh completed field survey.
3 Determination of existing methods for specialization of the left-hand lane in the zone of an adjustable intersection

An analysis of the main regulated intersections of 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») (fig. 1);
2. Organization of the movement of the left turn from a specialized lane in one phase of regulation («method 2») (fig. 2);
3. Organization of a left turn from a specialized lane together with the use of an «elongated regulation phase» («method 3») (fig. 3);
4. Organization of a left turn from a specialized lane in a specialized phase of regulation («method 4») (fig. 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 (fig. 1-4).

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 [8-10]. 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.

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.
In order to determine the parameter values for each possible combination, within the framework of the study, it is 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 2 and 3.

**Table 2.** The ratio of N₁ and N₂ (one band)

| N₁ | 50  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| N₂ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 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|
| 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|
| 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|
| 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|
| 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|
| 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|
| 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|
| 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|

\[ K₁ = \frac{N₁}{N₂} = n = \{t_n = x_n; \ l_n = y_n; \ v_n = z_n\} \]  

(1)

where \( K₁ \) - is the coefficient of the ratio of \( N₁ \) to \( N₂ \), \( N₁ \) - intensity of movement of the left turn, units/h; \( N₂ \) - the intensity of the movement of a direct conflicting stream moving in one lane, units h; \( n \) - is the value of the ratio coefficient (0.02 ... 4.0); \( t_n \) - delay time of the vehicle, s.; \( x_n \) - is 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; \( z_n \) - is the value of the speed of movement, for a given ratio of intensity, km/h.

**Table 3.** The ratio of N₁ and N₂ (two stripes)

| N₁ | 50  | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 | 700 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| N₂ |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 500| 0.1 | 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|
| 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|
| 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|
| 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|
| 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|
| 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|
| 3500| 0.01| 0.03| 0.04| 0.06| 0.07| 0.09| 0.10| 0.11| 0.13| 0.14| 0.16| 0.17| 0.19| 0.20|
| 4000| 0.01| 0.03| 0.04| 0.05| 0.06| 0.08| 0.09| 0.10| 0.11| 0.13| 0.14| 0.15| 0.16| 0.18|

\[ K₁ = \frac{N₁}{N₂} = n = \{t_n = x_n; \ l_n = y_n; \ v_n = z_n\} \]  

(2)

where \( K₁ \) - is the coefficient of the ratio of \( N₁ \) to \( N₂ \), \( N₁ \) - intensity of movement of the left turn, units/h; \( N₂ \) - the intensity of the movement of a direct conflicting stream moving in one lane, units h; \( n \) - is the value of the ratio coefficient (0.02 ... 4.0); \( t_n \) - delay time of the
vehicle, $s_n$; $x_n$ - is 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; $z_n$ - is the value of the speed of movement, for a given ratio of intensity, km/h.

The difficulty of using the presented coefficients lies in the coincidence of some values of the coefficients, which are characterized by different values of the studied parameters, in connection with this, the next stage of the study is the development of a decision algorithm for entering the previously considered methods (fig. 1-4) for organizing the movement of left turn in zone of an adjustable intersection.

4 Development of an algorithm for choosing left-turning lane specialization in an area of an adjustable intersection

To determine the necessary way of organizing traffic at a regulated intersection, out of the four previously considered (fig. 1-4), it is necessary to interpret the obtained values of vehicle delays with the existing service levels of the regulated intersection (Table 4).

| Service level | Control Delay (sec/aut) |
|---------------|------------------------|
| A             | ≤10                    |
| B             | 10 – 20                |
| C             | 20 – 35                |
| D             | 35 – 55                |
| E             | 55 – 80                |
| F             | >80                    |

Service level A: A small delay in regulation is up to 10 (sec/aut). Achieved when most of the cars arrive at the intersection and pass it on a green signal.

Service level B: The amount of control delay is between 10 and 20 (sec/aut). This is achieved with a fairly good progression (when most of the cars arrive on a green signal) or a short regulation cycle. The number of cars stopped is increasing compared to service level A.

Service level C: The amount of control delay is between 20 and 35 (sec/aut). Achieved with a long regulation cycle, poor progression. The number of cars stopped is significant, but, nevertheless, a significant part of the cars pass the intersection without stops.

Service level D: The amount of control delay is between 35 and 55 (sec/aut). Almost all cars stop. The presence of a high ratio of traffic intensity to bandwidth. The number of oversaturated cycles (saturation coefficient greater than 1) is very large.

Service level E: The amount of control delay is between 55 and 80 (sec/aut). In most of the cycles, oversaturation is observed (saturation coefficient is greater than 1).

Service level F: The amount of control delay is in the range of 80 or more (sec / aut). This level of service is considered unacceptable to most drivers.

Depending on what delays of vehicles exist at the research object, in order to construct an algorithm for choosing the method of organizing traffic of the left-hand flow, delays should be differentiated by the level of service of vehicles.

A further result of the developed method, namely, the approach using the introduced correlation coefficient, was the analysis of the corresponding limits according to the level of service, characterized by a peculiar value of the delay of vehicles. For each service level, a mathematical model was obtained that determines the dependence of the intensity parameters of the conflict in question and the delay value of the cars. As a result of the performed mathematical analysis and the obtained dependences, at the next stage, an algorithm was developed for choosing the necessary method for organizing the movement...
of the left turn in the area of the regulated intersection (fig. 5). Based on the analysis of changes in the main characteristics 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 a ratio coefficient that 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 associating 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.

Fig. 5. The proposed algorithm for selecting the necessary method of organizing the movement of the left-hand flow at an adjustable intersection

As a result of the mathematical analysis of the conflict in question, an algorithm for choosing the necessary method of organizing traffic in a regulated area was developed, a detailed justification for the selection was made, and the main parameters for changing the characteristics of the traffic flow were considered. In order to test the developed algorithm at the main busy intersection in Voronezh, an experiment was carried out to determine the necessary way to organize the movement of the left turn.

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. 6, 7).

Fig. 6. Satellite image of the object of study
Fig. 7. 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%.

6 Conclusions

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, an algorithm for arranging the left turn in the area of the regulated intersection was proposed. 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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