Methods for determining transport delays at simple intersections

M K Bedanokov, Y H Guketlev, A Z Udzhukhu, A S Labutin
Engineering Faculty, MSTU, 191, Pervomayskaya str., Maikop, 385000, Russia
E-mail: bedan64@mail.ru

Abstract. The article analyzes the flow of traffic to the city of Maikop. Existing methods for determining transport delays at intersections have been considered. It is established that the assessment of transport delays at intersections with a railway crossing is important from the point of view of traffic safety. The subject of the study is the intersection of Pushkin and Zheleznodorozhnaya streets in Maikop. The object of the study is the transport delay at this intersection. A new approach for transport delay calculating has been proposed. Preliminary results of the study have been presented; the author's formula for calculating transport delays has been given. The proposed method for transport delay calculating at another intersection has been verified.

1. Introduction
The modern development of society leads to the fact that motor vehicle fleet has been growing continuously and constantly over the years, that is, the growth rate of the number of cars remains stably high [1]. At the same time, the road network remains virtually unchanged. The consequences of this imbalance can be observed in almost any city in Russia: it is either constant traffic jams in large cities, or traffic jams during rush hours in small towns. In this regard, transport delays increase significantly.

In our opinion, traffic delay is one of the main characteristics of traffic, which can most fully characterize the interaction of the organization of traffic, the traffic capacity of intersections (section of a road) and the traffic flow intensity. In recent years, works have begun to appear related to transport delays at traffic lights [2, 3] and at pedestrian crossings [4, 5].

The increase in transport delays has a number of negative consequences, which include increased emissions, economic losses, reduced speed, etc. Besides, traffic delays contribute to psychophysiological fatigue of drivers, which leads to an increase in the number of conflict situations and accidents. One of the factors for increasing emergency situations is that drivers tend to drive through this intersection as quickly as possible, and most often they violate traffic rules. This is especially evident at railway crossings. Despite the fact that most railway crossings are equipped with barriers, the statistics of accidents at railway crossings remains stably high in Russia [6] (Figure 1).

Figure 1 shows that over the past four years, on average, at least one person has been injured or hurt in every accident, and every third accident has caused death. These statistics and a significant number of injured people and deaths at railway crossings show that improving road safety at railway crossings is an important task.
Consequently, determination of transport delays in an area of intersections of highways near railway crossings as one of the factors of road safety will allow us to assess the state of traffic organization at this intersection. Adoption of necessary measures for the optimal organization of traffic is a prerequisite for reducing accidents at road intersections.

![Figure 1. Road accident statistics at railway crossings](image)

### 2. Analysis of the flow of traffic to the city of Maikop

The city of Maikop is located in the southern Russia and it is the capital of the Republic of Adygeya. The road network through Maikop is the shortest way to a number of large cities in the southern Russia, the tourist cluster and the Black Sea coast. A multiple increase in transit flow through Maikop is expected with the setting the bridge across the Kerch Strait into operation.

The city of Maikop has mostly a rectangular layout (Figure 2). Entrance and exit of road transport to and out of the city of Maikop is carried out in 5 directions. Three of these directions have intersections (No. 7–9; Figure 2) located next to the railway. As a rule, the largest traffic flow at these intersections comes from the secondary direction. This leads to the fact that there are significant automobile queues in the secondary directions that can reach 300 meters or more (Figure 3, 4).

Due to a high traffic load at the crossing on Hakurate Street (No. 8, Figure 2) this crossing is closed for reconstruction, since a two-level interchange is being constructed at this intersection. Analysis of traffic flows by the example of the city of Maikop shows that the largest load at simple intersections is observed at intersections located near the railway. Significant queues can be observed in secondary directions at relatively low traffic intensities at such crossings.

### 3. Existing methods for determining transport delays

In our opinion, all methods for determining transport delays can be divided into two groups: field methods and analytical ones. Each of these methods has its advantages and disadvantages. Let us consider each of these methods briefly.

All methods for determining transport delays during direct work with the traffic flow at an intersection are referred to the field methods. These methods are described in a number of works [9–11]. The advantage of the field method is that it helps to obtain the most reliable results. It should...
also be noted that only field observations provide initial data for all other methods of traffic research. The disadvantage of this method is that it is labor-consuming and requires participation of several people to carry out measurements.

It should be noted that modern means of video recording and digital data processing can significantly simplify the complexity of field methods.

![Figure 2](image2.png)

**Figure 2.** The scheme of traffic flows to Maikop. 1, 2, 3, 4, 5 – directions of entry and exit of motor vehicles in the city of Maikop; 6 – railway; 7, 8, 9 – intersections of highways located near the railway.

![Figure 3](image3.png)

**Figure 3.** The car queue at the intersection of Adygeyskaya and Promyshlennaya streets
Figure 4. The queue of cars at the intersection of Pushkin and Zheleznodorozhnaya streets

In our opinion, analytical methods include both calculation formulas and results of traffic modeling at intersections. The most popular approach for calculating transport delays was proposed by Professor Yu.A. Kremenets [9]. This approach consists in the following: components of transport losses, even at constant traffic intensities on intersecting roads, vary over large ranges and are different for each vehicle.

The time spent is estimated by an average delay of one vehicle $t_{\Delta H}$, which is calculated considering the influence of many different indicators, if there are some indicators. Below there is a general view of an average delay:

$$t_{\Delta H} = t_{\Delta H_1} + t_{\Delta H_2} + t_{\Delta H_3}$$

where $t_{\Delta H_1}$ is average time spent while waiting for an acceptable interval, c;

$t_{\Delta H_2}$ and $t_{\Delta H_3}$ indicate average time that a car spends in a queue on the secondary road, and the vehicle deceleration time before the intersection, c.

In the case of constant deceleration and acceleration in the process of changing speed and the exponential distribution of time intervals between vehicles on the main road, the average delay of the vehicle in this direction of secondary junction is:

$$t_{\Delta H} = \frac{e^{N_m \cdot t_b} - N_m \cdot t_b - 1}{N_m - N_s \cdot (e^{N_m \cdot t_b} - N_m \cdot t_b - 1)} + \frac{V_a}{7.2} \left( \frac{1}{a_T} + \frac{1}{a_p} \right)$$

where $e$ is Napierian base;
N_m is traffic flow intensity on the main road in both directions, v/s;
N_s is intensity per average secondary road lane in the considered traffic direction, v/s;
V_a is vehicle speed on the main road, km/h;
t_b is boundary interval, s;
a_T and a_P are deceleration and acceleration respectively, m/s^2.

The average vehicle delay \( t_{\Delta H} \) at the intersection is defined as the weighted average value of the delays for all directions (approaches to an intersection) of the secondary road, calculated according to the formula (2) [9]:

\[
\bar{t}_{\Delta H} = \frac{\sum_{j=1}^{n} \left( t_{\Delta H_j} \cdot N_j \right)}{\sum_{j=1}^{n} N_j}
\]

(3)

where N_j is traffic intensity on the j-direction of the secondary road, v/h; n is a number of directions (approaches to the intersection) of the secondary road.

The disadvantage of the above approach is that the accuracy of calculations is not always acceptable.

4. Authors’ research to determine transport delays

At present video fixation devices are becoming increasingly important in road traffic organization. The cameras provide information on traffic flow in a continuous mode and thereby contribute to road safety.

4.1. Characteristics of intersection no. 9

To obtain data on traffic delays at intersection 9, we used a video camera to record traffic flows. The traffic management diagram at this intersection is shown in Figure 5.

The traffic management diagram at intersection 9 of Pushkin Street and Zheleznodorozhnaya Street is shown in Figure 5. Both Pushkin Street and Zheleznodorozhnaya Street have two lanes.

This crossing serves as a link between the city center and the Lago-Naki and Guzeriple tourism cluster.

A number of pedestrians crossing the railway in the crossing area is insignificant. Public transport passes through the crossing.

The crossing is equipped with a traffic light and an automatic barrier. The traffic direction at the intersection is shown in Figure 5; approximate traffic intensity is shown in Figure 6.

The largest lines of automobile transport in length and time are observed from direction 4 (Figure 6). From this direction, the motor vehicle turns left. This direction makes the main contribution to the average vehicle delay (3).

4.2. Regression equations for transport delay determination

The transport delay at the intersection was determined by the queue length. We fixed the initial time. At given time, the queue length was counted from direction 4. It was considered constant until the first car in the queue turned left. The time and the length of the queue were recorded again. If the queue increased, then it was assumed that the queue increased at the moment when the first vehicle drove away. Similarly, the time and length of the queue were recorded after each vehicle that turned left. Thus, you can get delay for each vehicle in the queue for the entire observation time.

According to the results of the research, we received queueing time for each car. Using these data we constructed a graph of the dependence of a vehicle idle time on the queue length (Figure 8). The sum of a vehicle idle time gave a transport delay in this direction.
Figure 5. The intersection of Pushkin and Zheleznodorozhnaya streets

Figure 6. Traffic directions at the intersection of Pushkin and Zheleznodorozhnaya Streets

Figure 7. Traffic intensity at the intersection of Pushkin and Zheleznodorozhnaya streets
4.3. Development of a model for determining transport delays

We propose to consider the following approach to accounting traffic intensity: turning to the left from direction 4 (Figure 6) is prevented by the movement of vehicles from directions 1, 2, 7, 8, 11, 12. These directions are considered to be the main directions relatively to direction 4. The other directions do not interfere with the movement of vehicles from direction 4. The following factors affect the...
amount of transport delay (or the length of vehicle queue) from direction 4; traffic intensity from direction 4 and traffic intensities from directions 1, 2, 7, 8, 11, 12. Obviously, we can consider the sum of the intensities of movements from directions 1, 2, 7, 8, 11, 12, because the movement of vehicles from these directions is an obstacle for vehicles from direction 4.

We can assume that the magnitude of the transport delay at the investigated intersection depends linearly on the above parameters. Let’s denote the total intensity of movement in the directions 1, 2, 7, 8, 11, 12 by \( X_1 \) and traffic intensity in direction 4 by \( X_2 \). Then the transport delay can be represented as the following expression:

\[
Y = k_1X_1 + k_2X_2 + C
\]  

(4)

where \( Y \) is transport delay, \( k_1 \) and \( k_2 \) are arbitrary coefficients, \( C \) is an intercept term.

Thus, to determine the transport delay, it is necessary to investigate the interaction of two factors that is to conduct a two-factor analysis.

After the two-factor analysis, the following regression equation is obtained:

\[
Y = 51.4476 + 1.1171X_1 + 0.2081X_2
\]  

(5)

### 4.4. Comparison of transport delay determination results

To verify formulas (4, 5, 7) calculations of the transport delay at the considered intersection have been made; the results of hourly observations at different times and on different days have been taken as initial data. Some results on measurements of one hour are presented in Table 1.

| No. | The number of passing cars in the main directions (1, 2, 7, 8, 11, 12) | A number of passing cars in a secondary direction (4) | Secondary direction Queue length (vehicles) | Experimental transport delay in the secondary direction (s) | Transport delay (formula 4) | Inaccuracy % | Transport delay (formula 5) | Inaccuracy % |
|-----|-------------------------------------------------|------------------------------------------------|--------------------------------------------|-------------------------------------------------|--------------------------|--------------|----------------------------|--------------|
| 1   | 47                                             | 36                                           | 15                                         | 92                                              | 0.61                     | 111.44       | 111.44                     | 21.13        |
| 2   | 46                                             | 35                                           | 15                                         | 102                                             | 0.45                     | 110.12       | 110.12                     | 7.96         |
| 3   | 45                                             | 32                                           | 13                                         | 92                                              | -0.05                    | 108.38       | 108.38                     | 17.80        |
| 4   | 44                                             | 33                                           | 14                                         | 126                                             | 0.09                     | 107.47       | 107.47                     | -14.71       |
| 5   | 49                                             | 27                                           | 13                                         | 129                                             | -0.97                    | 111.80       | 111.80                     | -13.33       |
| 6   | 50                                             | 28                                           | 15                                         | 119                                             | -0.71                    | 113.13       | 113.13                     | -4.93        |
| 7   | 51                                             | 25                                           | 12                                         | 124                                             | -1.43                    | 113.62       | 113.62                     | -8.37        |
| 8   | 52                                             | 24                                           | 11                                         | 117                                             | -1.70                    | 114.53       | 114.53                     | -2.11        |
| 9   | 61                                             | 29                                           | 13                                         | 121                                             | -0.30                    | 125.63       | 125.63                     | 3.82         |
| 10  | 62                                             | 30                                           | 13                                         | 118                                             | -0.10                    | 126.95       | 126.95                     | 7.59         |
| 11  | 52                                             | 32                                           | 9                                          | 107                                             | 0.11                     | 116.20       | 116.20                     | 8.59         |
| 12  | 51                                             | 31                                           | 10                                         | 103                                             | -0.08                    | 114.87       | 114.87                     | 11.53        |
| 13  | 57                                             | 27                                           | 16                                         | 98                                              | -0.78                    | 120.74       | 120.74                     | 23.21        |
| 14  | 57                                             | 26                                           | 14                                         | 119                                             | -1.02                    | 120.53       | 120.53                     | 1.29         |
| 15  | 49                                             | 25                                           | 13                                         | 120                                             | -1.50                    | 111.39       | 111.39                     | -7.18        |
| 16  | 50                                             | 25                                           | 13                                         | 97                                              | -1.47                    | 112.51       | 112.51                     | 15.98        |
| 17  | 54                                             | 24                                           | 12                                         | 99                                              | -1.64                    | 116.77       | 116.77                     | 17.94        |
| 18  | 53                                             | 24                                           | 12                                         | 91                                              | -1.67                    | 115.65       | 115.65                     | 27.09        |
| 19  | 49                                             | 29                                           | 13                                         | 104                                             | -0.52                    | 112.22       | 112.22                     | 7.90         |
| 20  | 50                                             | 29                                           | 12                                         | 135                                             | -0.49                    | 113.34       | 113.34                     | -16.05       |
| 21  | 50                                             | 31                                           | 12                                         | 118                                             | -0.10                    | 113.75       | 113.75                     | -3.60        |
| 22  | 51                                             | 30                                           | 13                                         | 134                                             | -0.27                    | 114.66       | 114.66                     | -14.43       |
| 23  | 55                                             | 28                                           | 13                                         | 125                                             | -0.59                    | 118.71       | 118.71                     | -5.03        |
| 24  | 55                                             | 27                                           | 13                                         | 123                                             | -0.82                    | 118.51       | 118.51                     | -3.65        |
| Total | 2713                                          |                                               |                                            | 2763                                          | 45.62                    | 832           | 832                        | 100          |
The analysis of the above table shows that the maximum inaccuracy of the transport delay is 27% using formula (5). However, the total estimated hourly transport delay (2763 s) differs from the experimental one (2713 s) by 1.8%.

4.5. Verification of the obtained equation at intersection No. 7 of Adygeyskaya and Promyshlennaya streets

To verify the obtained formula in the form of a regression equation (5), the transport delay in the secondary direction at intersection No. 7 of Adygeyskaya and Promyshlennaya streets has been calculated. The obtained transport delay values have been compared with experimental data. The intersection pattern is similar to the intersection of Pushkina Street and Zheleznodorozhnaya Street (Figure 4). The calculation results are presented in the form of Table 2. The results of the calculations of the transport delay according to formula (2) are also shown in this table.

Table 2. The results of the transport delay calculations at intersection No. 7 according to the formulas (2, 5)

| №  | The number of passing cars in the main directions (1, 2, 7, 8, 11, 12) | A number of passing cars in a secondary direction (4) | Secondary direction Queue length (vehicles) | Experimental transport delay in the secondary direction, s | Transport delay (formula 2), s | Transport delay (formula 5), s | Inaccuracy, % |
|----|---------------------------------------------------------------|-----------------------------------------------------|--------------------------------------------|------------------------------------------------------|----------------------------|----------------------------|--------------|
| 1  | 58                                                            | 36                                                  | 15                                         | 112                                                  | 0.76                      | 123.73                    | 10.47        |
| 2  | 57                                                            | 35                                                  | 15                                         | 135                                                  | 0.62                      | 122.41                    | -9.33        |
| 3  | 63                                                            | 32                                                  | 13                                         | 139                                                  | 0.25                      | 128.48                    | -7.57        |
| 4  | 63                                                            | 33                                                  | 14                                         | 119                                                  | 0.40                      | 128.69                    | 8.14         |
| 5  | 69                                                            | 27                                                  | 13                                         | 125                                                  | -0.62                     | 134.15                    | 7.32         |
| 6  | 68                                                            | 28                                                  | 15                                         | 129                                                  | -0.42                     | 133.24                    | 3.28         |
| 7  | 62                                                            | 25                                                  | 12                                         | 140                                                  | -1.18                     | 125.91                    | 10.06        |
| 8  | 61                                                            | 24                                                  | 11                                         | 143                                                  | -1.47                     | 124.59                    | 12.88        |
| 9  | 59                                                            | 29                                                  | 13                                         | 132                                                  | -0.32                     | 123.39                    | 6.52         |
| 10 | 60                                                            | 30                                                  | 13                                         | 129                                                  | -0.12                     | 124.72                    | 3.32         |
| 11 | 63                                                            | 32                                                  | 9                                          | 116                                                  | 0.25                      | 128.48                    | 10.76        |
| 12 | 64                                                            | 31                                                  | 10                                         | 119                                                  | 0.10                      | 129.39                    | 8.73         |
| 13 | 57                                                            | 27                                                  | 16                                         | 101                                                  | -0.78                     | 120.74                    | 19.55        |
| 14 | 58                                                            | 26                                                  | 14                                         | 133                                                  | -1.00                     | 121.65                    | 8.53         |
| 15 | 51                                                            | 25                                                  | 13                                         | 120                                                  | -1.43                     | 113.62                    | 5.31         |
| 16 | 52                                                            | 25                                                  | 13                                         | 137                                                  | -1.40                     | 114.74                    | 16.25        |
| 17 | 54                                                            | 24                                                  | 12                                         | 141                                                  | -1.64                     | 116.77                    | 17.19        |
| 18 | 53                                                            | 24                                                  | 12                                         | 135                                                  | -1.67                     | 115.65                    | 14.33        |
| 19 | 57                                                            | 29                                                  | 13                                         | 129                                                  | -0.35                     | 121.16                    | 6.08         |
| 20 | 58                                                            | 29                                                  | 12                                         | 119                                                  | -0.34                     | 122.27                    | 2.75         |
| 21 | 55                                                            | 31                                                  | 12                                         | 126                                                  | -0.01                     | 119.34                    | 5.29         |
| 22 | 55                                                            | 30                                                  | 13                                         | 123                                                  | -0.19                     | 119.13                    | 3.15         |
| 23 | 54                                                            | 28                                                  | 13                                         | 122                                                  | -0.61                     | 117.60                    | 3.61         |
| 24 | 53                                                            | 27                                                  | 13                                         | 128                                                  | -0.86                     | 116.27                    | 9.16         |

| Total | 3052 | -12.05 | 2946.12 |

Table 2 shows that the maximum accuracy in calculating the transport delay by the formula (5) does not exceed ± 20 %.

The estimated transport hour delay at this intersection (2946 s) differs from the experimental one (3052 s) by 3.5 %. Thus, the preliminary obtained result using formula (5) for determining the transport delay shows a high level of correlation.
Obviously, further research is needed for the development of the proposed approach. A significant advantage of the proposed approach, the result of which is expression 5, is its simplicity of calculation, in contrast to expression (2).

5. Conclusion

The following work has been carried out in the research:

• Experimental data in the form of video files have been collected.
  • The experimental data have been processed, as a result, a graph of the dependence of the transport delay on the queue length has been obtained (Figure 8).
  • A new approach has been proposed for determining transport delays. The equation (5) has been obtained, that shows the dependence between transport delay and traffic intensity.
  • The initial data obtained as a result of the experiment for the investigated intersection and the results calculated by the formula (5) are presented in Table 1.
  • The transport delay has been calculated using the formula (5) at another intersection (No. 7), and Table 2 has been constructed on the basis of the results. A rather high accuracy of determining the transport delay has been obtained.

References

[1] Akhunova I B and Udzhukhu A Z 2017 On some additional directions to the tasks in the Federal target program “Improving Road Safety” Bulletin of transport information. Information and practical journal 3(261) 33–5
[2] Andronov R V and Leverenz E E 2017 Calculation of vehicle delays at an isolated regulated intersection during its operation at high loading levels using Monte Carlo method Bulletin of Civil Engineers 1(60) 221–6
[3] Boyarsky S N 2015 Improving the efficiency of highway intersection with a high value of the traffic load factor The dissertation for the degree of Candidate of Technical sciences (Yekaterinburg)
[4] Saha A, Ghosh I and Chandra S 2017 Delay at Signalized Intersections under Mixed Traffic Conditions Journal of Transportation Engineering 143(8)
[5] Preethi P, AbyVarghese and Ashalath R 2016 Modelling Delay at Signalized Intersections under Heterogeneous Traffic Conditions Transportation Research Procedia 17 529–38
[6] Naumova N A 2018 Method for determining vehicle delays at intersections, taking into account pedestrian traffic Modern high-tech technologies 8 116–20
[7] Chikalin E N 2012 Analysis of transport delays at unregulated pedestrian crossings Bulletin of Irkutsk State Technical University 9(68) 168–74
[8] Road safety indicators. Retrieved from: http://stat.gibdd.ru
[9] Kremenets Yu A, Pechersky M P and Afanasyev M B 2005 Technical means of traffic management (Moscow, “Academkniga” ICC)
[10] Bulavina L V 2009 An experimental study of the characteristics of transport and pedestrian traffic (Yekaterinburg)
[11] TranspoVolume. Retrieved from: http://www.transpovolume.ru/ranvols-878-1.html