Assessment of the level of influence of weather conditions on the mode of operation of the regulated intersection

Anastasia Shevtsova^{1,*}, Andrey Kravchenko¹, and Victoria Vasilyeva²

¹ Belgorod State Technological University named after V. G. Shukhov, Belgorod, 308012, Russia

² Orel State University named after I.S. Turgenev, Orel, 302026, Russia

Abstract. This article analyses the influence of weather conditions on the mode of operation of a regulated intersection. As a result of the analysis of regulatory and scientific sources, the authors established a connection between the temperature conditions of the environment and the movement of vehicles in the area of a regulated intersection. The established dependence on the result of the experiment allows us to optimize the traffic light control cycle and coordination programs depending on temperature differences, which allows more efficient control of traffic flows in the area of the regulated intersection.

1 Introduction

One of the most important principles of traffic management is safety. However, there are a number of other criteria that must be considered when organizing traffic. All these criteria are related to the efficiency of the transport process. The natural desire of any person is to minimize the time of movement. Thus, the organization of traffic on the road network is always a compromise between safety and efficiency of the transport process. This means that the speed of vehicles in a section of the road network should be as high as possible, based on the implementation of the required level of safety in this section.

The task of organizing traffic, as a rule, is solved for specific, in most cases, «good», traffic conditions. However, over time, for one reason or another, conditions on the same section of the road network may change. One of these factors is the weather and climate conditions. For the Russian Federation, this factor is especially relevant, because most regions of Russia are subject to constant changes in weather conditions, this issue is especially acute when managing traffic flows in the zone of regulated intersections.

2 Study of methods for determining weather conditions

There are several weather phenomena that have the greatest impact on traffic patterns and safety. These include snow, rain, fog and ice, because it is these weather phenomena that have the greatest impact on changing one of the most important safety criteria: adhesion

* Corresponding author: shevcova-anastasiya@mail.ru

coefficient and visibility distance. Consider the effect of each phenomenon on the mode of movement of the car.

The main danger when driving in rainy weather is the deterioration of the adhesion of the wheels to the road surface. On wet roads, the coefficient of adhesion decreases by 1.5–2 times, and this, in turn, leads to an increase in braking distance and a deterioration in the stability of cars [1-5].

The rain that has just begun is dangerous, which makes the road surface very slippery, since dust, the smallest particles of tires, soot particles and oil from the exhaust pipes of cars are wetted and spread along the road, creating a very slippery film on it. As the rain intensifies and continues, the mud film is washed off by the rain and with prolonged rain the coefficient of adhesion to the road increases again. After the rain stops, as the mud dries, it first turns into a dirty slippery film, and the coefficient of adhesion decreases again. As the road dries, the dirt turns to dust, and the coefficient of adhesion is restored. The dependence of the coefficient of adhesion to the road on the duration of the rain is shown in fig. 1, where time $t_0 - t_1$ is the beginning of rain; time $t_1 - t_2$ - rain duration; time $t_2 - t_3$ - drying time of the road

Fig. 1. The dependence of the coefficient of adhesion of the wheels of the car with the road on the duration of the rain

As a result of a study of scientific literature, it was found that weather conditions are directly related to the temperature of the road surface, which in turn has an effect on the coefficient of adhesion and, as a consequence, on the modes of movement of vehicles.

3 The main methods for determining the temperature of the pavement

There are several methods for determining the temperature of the pavement:

The first is the method of determining the temperature of the pavement using the points of road weather monitoring, created on the basis of automatic road weather stations with a set of sensors that measure meteorological parameters and surface conditions of the road surface. Modern stations can measure the following parameters: air temperature, relative humidity, precipitation intensity, type of precipitation, amount of precipitation, atmospheric pressure, wind direction, wind speed, surface temperature of the road surface, temperature under the surface of the road surface. The number of measured parameters and the speed of processing and transmitting information depend on the design of the weather station.

Despite the wide possibilities of using the stations, their main disadvantage is the high cost. High investment does not allow the use of stations everywhere. They are installed, as a rule, on high-speed motorways and at the entrances to large cities.

The second method is based on establishing the relationship between the ambient temperature and the temperature of the pavement. As you know, the temperature of the asphalt concrete pavement is a function of air temperature, and it substantially depends on solar radiation, the course of temperatures in the subgrade, as well as on many other factors.

At different times, a large number of researchers studied the relationship between air and pavement temperatures. The analysis of experimental data shows that the most accurately calculated surface temperature of the asphalt concrete pavement can be determined depending on the ambient temperature in the form of a broken line drawn through 3 points that correspond to the maximum, minimum and average annual air temperatures.

Methods for calculating the maximum and minimum temperatures of asphalt concrete pavements are given in the works of many researchers. So, Ya.N. Kovalev in his research work [6] proposes to determine the minimum temperature of an asphalt concrete pavement using the following formula:

$$T_s^{min} = 0,7T_a^{min} \quad (1)$$

where T_s^{min} – estimated minimum surface temperature, °C; T_a^{min} – minimum outside temperature, °C.

At the end of the 80s, the United States was actively developing methods for improving operational performance and service life of the road and improving road safety. The new method was called “Superpave” (Superior Performance Pavements) and replaced the already obsolete methods “Hveem” and “Marshall” [7]. The main points of this method were formulated from 1987 to 1993 as part of the strategic road research program (SHRP) with the involvement of the Asphalt Institute and other leading US universities.

The development of the Superpave method was associated with large-scale field studies in regions with different climates to determine the estimated temperatures of asphalt concrete pavements. A large volume of measurements of the surface temperature of asphalt concrete pavements was made in Canada. As a result of processing the measurement data, the Robertson dependence (1987) was confirmed, linking the minimum surface temperature of the asphalt concrete pavement and the minimum ambient temperature:

$$T_s^{min} = 0,859T_{min} + 1,7 \quad (2)$$

where T_{min} – minimum average air temperature based on meteorological data, °C.

In his research A.E. Borovskoy and A.G. Shevtsova [8-10], established that weather and climate factors affect the mode of operation of a traffic light object and proposed the use of an improved methodology for calculating the traffic light control cycle, this technique establishes the dependence of the saturation flux on the adhesion coefficient. Joint use of the HCM 2000 methodology [11] and the method proposed by A.E. Borovsky and A.G. Shevtsova allows you to create a traffic light algorithm that can adapt to changing weather conditions.

4 Algorithm for weather conditions in the area of the regulated intersection

During the research, the authors developed an algorithm that allows you to take into account changes in weather conditions in the area of the regulated intersection, which includes 6 stages:

Stage 1. Receiving and processing data on ambient temperature and humidity. Using sensors of temperature and humidity of the ambient air, we determine the current values of the environmental parameters.

Stage 2. Analysis of the data and determination of the temperature of the coating. According to the values of Construction Climatology [12], the minimum air temperature of the coldest five-day security of 0.98 in the city of Belgorod is -27 °C. For Belgorod, the maximum temperature is 38 ° C. the average annual temperature is at around 6.4 °C.

Stage 3. Determination of adhesion coefficient. The analysis of the dependence of the coefficient of adhesion on air temperature showed that 8 temperature ranges can be distinguished in which the coefficient of adhesion changes:

- 1. - 20°C ... -10°C → φ =0.4;
- 2. - 9°C ... - 5°C → φ =0.3;
- 3. - 4°C ... - 3°C → φ =0.2;
- 4. - 2°C ... 0°C → φ =0.1;
- 5. 0°C ... 1°C → φ =0.3;
- 6. 1°C ... 2°C → φ =0.5;
- 7. 3°C ... 5°C → φ =0.6;
- 8. > 5°C → φ =0.65-0.7;

Stage 4. Defining a safety distance. The safety distance depends on the speed and the coefficient of traction of the vehicle’s tires. We divide the entire range of possible adhesion coefficients into 7 values (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7) and calculate the value of the safety distance for each of these values. In this case, we take the speed of traffic from the condition of ensuring traffic safety: for adhesion coefficients of 0.7 - 0.5, we take the estimated speed of movement equal to 60 km / h, for 0.4 → 50 km / h, 0.3 → 40 km / h, 0.2 → 30 km / h, 0 , 1 → 20 km / h. The data obtained are presented in table 29.

Stage 5. Determination of dynamic dimension. We determine the dynamic dimension. In the calculations, the overall length of the car is assumed to be 4.5 meters. The results are shown in table 1.

Table 1. Determination of basic saturation flow.

Adhesion coefficient	0,1	0,2	0,3	0,4	0,5	0,6	0,7
Speed of movement, m / s	5,6	8,3	11,1	13,9	16,7	16,7	16,7
Braking time, s	0,77	0,8	0,83	0,85	0,88	0,90	0,93
Safety distance, m	12,3	18,4	25,0	31,5	38,3	35,2	33,1
Dynamic dimension, m	16,8	22,9	29,5	36,0	42,8	39,7	37,6
Travel time, s	3,00	2,75	2,65	2,58	2,56	2,37	2,25
Basic saturation flow, units / h	1200	1309	1359	1395	1406	1518	1600

Stage 6. Determination of saturation flux. We determine the basic saturation flux. The results are shown in table 1.

5 Experiment

As an object of study, on which the proposed algorithm will be tested, there is a section of the road network in the city of Belgorod - the intersection of Belgorodsky Avenue - Bogdan Khmelnitsky Avenue. This intersection is an X-shaped intersection due to the intersection of traffic and pedestrian flows (fig. 2).

Fig. 2. A satellite image of the intersection of B. Khmelnitsky Prospect - Belgorod Ave. (Belgorod)

To implement the developed algorithm, it will be necessary to install air temperature sensors and precipitation sensors for reading environmental parameters, as well as installing TPI to inform traffic participants about the recommended speed on the highway.

The obtained algorithm of the traffic light signaling the research object is presented in table 2.

Table 2. Algorithm for enabling traffic signal programs at the object of study.

Ambient temperature, °C	Precipitation	Adhesion coefficient	Coordination program
from – 20°C before –10°C	No	0,4	4
from – 9°C before – 5°C		0,3	3
from – 4°C before – 3°C		0,2	2
from – 2°C before 0°C (inclusive)		0,1	1
from 0°C before 1°C (inclusive)		0,3	3
from 1°C before 2°C		0,5	5
from 3°C before 5°C		0,6	6
>5°C		0,65-0,7	7
from – 20°C before –10°C	Yes	0,3	3
from – 9°C before – 2°C		0,2	2
from – 1°C before 6°C		0,1	1
from 6°C before 7°C (inclusive)		0,3	3
from 7°C before 10°C		0,4	4
>11°C		0,5	5

In order to assess the effectiveness of the calculation and the rationality of its further use, we evaluate the parameters of the average delay time of cars at the intersection throughout the intersection using the simulation model (fig. 3).

Fig. 3. Change in the average delay time: a) before using the algorithm; b) after using the algorithm

Having calculated the delays in the traffic flow using the Aimsun software product [13], we can draw the following conclusion: at the intersection in all directions with the existing

88 s cycle, the average delay was ~ 71.9 s, after the calculated traffic light control mode taking into account changes in weather conditions during the cycle 90 s - the average delay decreases to 65 s. The average deviation is 10%.

6 Conclusions

The new calculated traffic light cycle improves the traffic situation at the intersection, the transport delay decreases, the number of passing vehicles per cycle increases. In the course of the work, a study was made of new parameters proposed for calculating traffic flow at a controlled intersection, namely, taking into account weather and climate conditions. Based on the developed algorithm, the mode of operation of a traffic light object at the intersection under study was calculated and a rational traffic light cycle reducing transport delays was proposed. The work of the traffic light object, taking into account the new cycle, was tested on a simulation model.

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