

ЗАЛІЗНИЧНА КОЛІЯ ТА АВТОМОБІЛЬНІ ДОРОГИ

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Determination of Reserves for Reducing Delays and Increasing the Capacity of the Street-Road Network in Gomel as a Factor of Reducing Losses in Traffic

Purpose. Often, the existing level of traffic capacity of road network facilities in large cities is insufficient. This is often due to the fact that urban growth is significantly ahead of the reconstruction and renovation of the corresponding infrastructure. As a result, traffic delays of various kinds occur on city roads, accompanied, first of all, by economic losses. Therefore, the search for reserves to reduce various types of losses associated with insufficient traffic capacity of the road network when organizing urban traffic is the purpose of this work. **Methodology** To determine the reserves for increasing the traffic capacity of the road network and reducing various kinds of delays, the method of deterministic analysis was used, the method for calculating the cycle according to F. Webster, based on the use of phase coefficients and time lost in the cycle (as the sum of transient intervals), the method for measuring the intensity of car traffic in the traffic flow, as well as the methodology for calculating economic losses arising from delays in the movement of vehicles. **Findings.** A study of delays and time expenditures and the corresponding economic losses that occur at typical objects of the city's street-road network (regulated intersections) has been carried out. The reserves of their reduction, and as a consequence, the increase in the capacity of both individual sections and the city's road network as a whole, have been determined. **Originality.** The use of this method on real objects of the road network allows developing the scientific interpretation of the methods used and expanding the scope of their application. **Practical value.** Assessment of emerging problems of traffic capacity and associated losses (including economic ones) makes it possible to determine the most promising ways to determine the traffic capacity reserves and, as a result, reduce economic losses.

Keywords: traffic capacity; road network; accident losses; economic losses; infrastructure; road traffic

Introduction

In one form or another, losses are present in all spheres of activity and, accordingly, have a different form – from wasted time to human losses. At the same time, almost any of them can be interpreted from the standpoint of the economy – to calculate economic losses using (if necessary) the cost estimates of objects and phenomena and the corresponding coefficients. Losses in road traffic are classified into economic, environmental, accident and social. In terms of scale, economic losses significantly exceed all combined. In addition, this type significantly affects the level of well-being of the population of our country, however, they are

masked and merge with really inevitable costs, as a result they get used to them and they seem to be not noticed. However, they are almost equally distributed among all members of society as various taxes. Economic losses mean unnecessary delays caused, for example, by a speed decrease in comparison with the norm, as well as stops and overruns of transport, delays of passengers and pedestrians, excessive fuel consumption, wear or damage to the vehicle due to poor-quality traffic conditions, etc.

Traffic loss is the socio-economic cost of the non-compelled costs of the driving process. When determining economic losses from traffic delays at a regulated intersection, a uniform speed of

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60 km/h is taken as the normative one. Anything that differs from this regime in the direction of decreasing speed and increasing unevenness is considered to be an unforced cost that causes losses. However, this speed at a controlled intersection is only possible for transit traffic flows. At the same time, for turning, especially for right-turning traffic flows, in most cases it is physically unattainable, since it is determined by a relatively small turning radius of the trajectory of traffic flows [2, 3, 4, 5, 8, 9].

Turning radii are determined by many factors, a certain number of which does not depend on the organization of traffic, therefore they must be measured, and not determined by calculation. Consequently, less than 60 km/h speed of turning traffic flows to some extent is a forced cost and does not lead to losses. Therefore, in each specific case, for turning traffic flows, it is necessary to determine the maximum speed, below which unforced costs begin, which already lead to losses. The determination of the reference speed of turning traffic flows is carried out taking into account the tasks being solved, depending on the turning radius of the trajectory of the movement, which is determined according to the scale plan of the object.

Purpose

The existing level of traffic capacity in large cities is rarely sufficient. This is often due to the fact that urban growth is significantly ahead of the reconstruction and renewal of the corresponding infrastructure. As a result, traffic delays of various kinds occur on city roads, accompanied primarily by economic losses. Therefore, finding opportunities to reduce various kinds of losses associated with insufficient traffic capacity of the road network when organizing urban traffic is the purpose of this work.

Methodology

To determine the reserves for increasing the traffic capacity of the road network and reducing various kinds of delays, the method of deterministic analysis was used, the method for calculating the cycle according to F. Webster, based on the use of phase coefficients and time lost in the cycle (as the sum of transient intervals), the method for measuring the intensity of car traffic in the traffic flow, as well as the methodology for calculating economic losses

arising from delays in the movement of vehicles. And Rankin's «Traffic Loss Determination» methodology was also used, with some changes corresponding to the specific object of the road network under study.

Findings

Economic losses at controlled intersections are usually calculated only for controlled traffic. Economic losses in uncontrolled traffic are insignificant – less than losses in controlled traffic, which is explained by the low traffic intensity, so they are not calculated. A certain compensation for these losses is made by choosing the annual fund of time for the operation of the road network facility and a certain increase in the estimated traffic intensity compared to the average value. Losses from traffic and pedestrian traffic costs are calculated. Among the costs of traffic, delays, stops, overrun and excessive fuel consumption are considered, and when pedestrians are moving, delays and overruns. Of greatest interest in the analysis of the object under consideration are the costs associated with the movement of vehicles. Transport delays and stops are calculated for each lane in each direction, and the losses caused by them are summed up within the intersection. Over-mileage and losses from it are determined only in the case of prohibition or assignment of turns, which, as a rule, is accompanied by over-mileage with all the ensuing consequences. Losses from excessive consumption of fuel are determined for the so-called calculated total traffic flow. Pedestrian delays are determined for each pedestrian crossing, and losses from them are added up within the intersection. Pedestrian re-passage and losses from it are determined only in the case of the closure of the pedestrian crossing or significant (more than 6 m from the pavement line) assignment of the crossing from the intersection [10].

Losses on the stretch are determined for transport from delays, stops, over-mileage and excessive fuel consumption. Stops on the stretch can occur in the event of overload, the presence of an unregulated pedestrian crossing, etc., delays can also occur when the average technical speed of the traffic flow differs from the normative one (60 km/h). In this case, losses from excessive fuel consumption are also determined. The overtravel

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often occurs outside the investigated stretch, however, the losses from the overtravel are calculated, since its cause lies in the investigated coordinated direction.

When determining the cost of unit costs, the value of the gross domestic product, the cost of fuel, the cost of the car and its operation, as well as the loss of profit by consumers (10% of the cost of costs) due to irrational use of the car are also taken into account.

The cost of excessive fuel consumption when calculating losses at a regulated intersection was included in the cost of delays, stops and overruns of transport and is not calculated separately. The numerical values of the specific overrun and specific overtravel are determined from the results of experimental measurements or are specified in the initial data. The values of specific delays, specific stops and specific fuel consumption are determined by calculation.

Using the example of a typical regulated intersection located in a residential area of Gomel-city, we will consider measures to reduce delays and thereby reduce economic losses.

This intersection connects Mazurova Street with entrances to sleeping areas and to the parking lot to the Almi and Vesta stores (Figure 1). Near this crossroads there are residential buildings, bus stops for route vehicles, various shops. Thus, the flow of vehicles is diverse (cars and trucks, public transport, etc.).

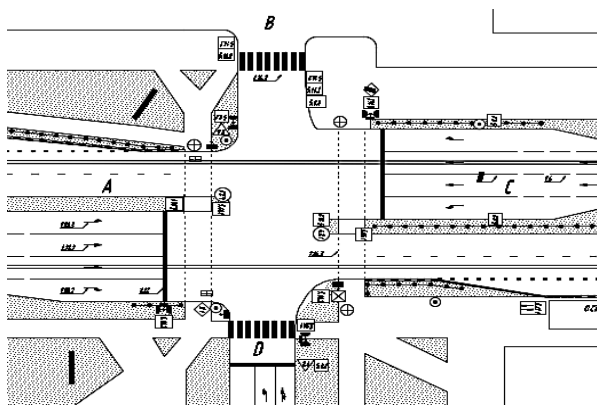


Fig. 1. The scheme of the investigated controlled intersection

The main road, Mazurova Street, has a G2 road category. Accordingly, there are two carriageways – 2 lanes in each direction (entrances A and C), the width of which is 4 m, however, when approaching

the intersection, there are additional lanes for making maneuvers (turns left and right). Secondary road – entrances to shops (entrances B and D) – they have three lanes (two of which face the intersection), at entrance B the width of each lane is 3.5 m, and at entrance D the width of the carriageway is 9 m. There is a dividing strip on the Mazurova Street. The main flows of vehicles move from entrances A and C, the direction of their movement is predominantly transit.

Traffic delays are a measure of the effectiveness of traffic management. At a controlled intersection, they primarily depend on the quality of the traffic light cycle, the optimization of which is one of the ways to reduce economic losses. The traffic light facility is one of the most significant places where economic losses are concentrated, mainly from delays and transport stops. In turn, delays and stops of transport are the most important indicators of the functioning of a traffic light object and their determination is necessary when calculating and optimizing a traffic light cycle [6, 7, 11, 12].

Knowing the average arrival rate $q=1/T$ and departure rate $q_H=1/T_H$, as well as the duration of the cycle (C) and the green signal (t_g), we can determine the total delay value by dividing it by the number of cars passed, defined as:

$$n = q \cdot C. \quad (1)$$

In the first, very rough approximation, it can be assumed that each stopped car is delayed for a time equal to half the time the red signal is on. Since for stopped cars, in the first approximation, the proportion of the red signal in the cycle is proportional, the specific delay is approximately equal to:

$$d \approx \left(\frac{t_{kp}}{2} \right) \cdot \left(\frac{t_{kp}}{C} \right) = \frac{t_{kp}^2}{2 \cdot C}, \text{ s} \quad (2)$$

where t_{kp} – duration of the prohibition signal on, s; C – duration of the traffic light cycle, s.

Considering that $t_{kp} = C \cdot (1 - \lambda)$, we can write:

$$d \approx \frac{C \cdot (1 - \lambda)^2}{2}, \quad (3)$$

where λ – the proportion of the green signal in the cycle:

$$\lambda = \frac{t_z}{C}, \quad (4)$$

where t_z – duration of green signal on, s.

This formula is used for rough calculations when evaluating options for organizing traffic on large sections of the road network, most often at the initial design stage. However, this formula does not take into account several very significant factors.

First, the arrival is far from uniform – both in terms of the number of arriving vehicles at the stop line per cycle, and the moment of their arrival within the cycle itself.

Departure of vehicles from stop lines (saturation flow) can be equally uneven, which is associated with the composition of the traffic flow, the location of vehicle types in front of the stop line (for example, trucks and buses first, and then cars, or vice versa), and also an extreme variety of driving conditions. Finally, relatively short-term overloads are possible, when not all vehicles manage to pass the stop line in a given cycle and remain for the second, or even the third - fourth cycle. Taking into account these factors and their combinations, the calculation of the transport delay becomes sharply complicated and it is almost impossible to obtain accurate values. Therefore, the approach proposed by F. Webster has gained widespread acceptance, which considers two components of the total delay - deterministic and random:

$$d = d_1 + d_2, \quad (5)$$

where d_1 – deterministic component, corresponding to the uniform arrival and departure of the vehicles; d_2 – the random component, taking into account the random nature of the arrival and departure of the vehicle.

In expanded form, Webster's formula takes the form:

$$d = \frac{C \cdot (1 - \lambda)^2}{2 \cdot (1 - \lambda \cdot X)} + \frac{X^2}{2 \cdot q \cdot (1 - X)} - 0.65 \cdot X^{2+5\lambda} \cdot \sqrt[3]{\frac{C}{q^2}}, \quad (6)$$

where X – the traffic load factor;

$$X = \frac{q}{q_H \cdot \lambda}, \quad (7)$$

where q – arrival rate, auto/s; q_H – saturation flux, auto/s.

It was found that the simplified Webster's formula gives good enough results:

$$d = 0.45 \cdot \left[\frac{C \cdot (1 - \lambda)^2}{1 - \lambda \cdot X} + \frac{X^2}{q \cdot (1 - X)} \right] \quad (8)$$

Webster's formula is not applicable in the area of very high loads, when $X \rightarrow 1$ and overloads, when $X > 1$, which is clearly seen from its structure, where the expression $(1 - X)$ stands in the denominator [1].

Pedestrian delays are determined by the formula:

$$d_n = 0.5 \cdot C \cdot (1 - \lambda_n)^2, \text{ s} \quad (9)$$

where λ_n – the percentage of green signal in the cycle for pedestrians.

For calculations, the lanes from entrance A will be considered. In ten traffic light cycles, 8 cars turned to the right, 17 cars turned left, 157 vehicles turned straight (from the left lane 95 vehicles, from the right 62). The intensity of traffic in the lane for turning to the right is 48 auto/h or 0.013 auto/s, along the lane for the left turn 102 auto/h or 0.028 auto/s, directly from the left lane – 570 auto/h or 0.16 auto/s, directly from the right lane – 372 auto/h or 0.1 auto/s.

Let us calculate the specific delay:

$$d \approx \frac{86 \cdot \left(1 - \frac{44}{86}\right)^2}{2} = 10.32 \text{ s.}$$

The load factor for each lane is:

$$X_{left} = 102 / (1800 \cdot 0.51) = 0.11;$$

$$X_{lstraight1} = 570 / (1800 \cdot 0.51) = 0.62;$$

$$X_{lstraight2} = 372 / (1800 \cdot 0.51) = 0.41;$$

$$X_{right} = 48 / (1800 \cdot 0.51) = 0.05$$

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Delay of vehicles is:

$$d_{left} = 0.45 \cdot \left[\frac{86 \cdot (1 - 0.51)^2}{1 - 0.51 \cdot 0.11} + \frac{0.11^2}{0.028 \cdot (1 - 0.11)} \right] = 10.1 \text{ s};$$

$$d_{straight1} = 0.45 \cdot \left[\frac{86 \cdot (1 - 0.51)^2}{1 - 0.51 \cdot 0.62} + \frac{0.62^2}{0.16 \cdot (1 - 0.62)} \right] = 16.4 \text{ s};$$

$$d_{straight2} = 0.45 \cdot \left[\frac{86 \cdot (1 - 0.51)^2}{1 - 0.51 \cdot 0.41} + \frac{0.41^2}{0.1 \cdot (1 - 0.41)} \right] = 13 \text{ s};$$

$$d_{right} = 0.45 \cdot \left[\frac{86 \cdot (1 - 0.51)^2}{1 - 0.51 \cdot 0.05} + \frac{0.05^2}{0.013 \cdot (1 - 0.05)} \right] = 9.6 \text{ s}.$$

Pedestrian delay is:

$$d_n = 0.5 \cdot 86 \cdot \left(1 - \frac{40}{86} \right)^2 = 12.3 \text{ s}$$

Traffic at the intersection under study is of high intensity and, as shown by the analysis results, there is a high value of vehicle and pedestrian delays. The investigated intersection is accepted for analysis as typical for the city of Gomel. The number of objects of the road transport network in the city with a similar configuration, traffic light control system and, as a consequence, and similar problems in the field of traffic management is quite large. In this regard, the data obtained can be used as an analytical base for a certain segment of the city's road network. From an economic point of view, the magnitude of the delays obtained can be characterized using the approved reduction coefficients, which take into account not only the magnitude of delays in seconds, but also their type (delays of pedestrians, vehicles of various types). Since the processes occurring in the world economy and the country's economy do not allow an unambiguous assessment of economic losses in national monetary units in the long term, the corresponding reduction coefficients can be used only taking into account the reduction to conventional

monetary units and subsequent conversion into the national currency as of a specific period. This approach will allow the obtained results to be as close to real ones as possible and will make them comparable in different time periods. The resulting value of economic losses from delays only at the considered intersection (as one of the most common types of intersections in Gomel-city among the objects of the road network) is about 5–6 thousand Belarusian rubles (or 2300 conventional monetary units) in year. However, if we take into account the losses associated with delays in the movement of specialized vehicles (ambulances, the Ministry of Emergency Situations, other specialized vehicles), then this amount may increase several times. If we take into account the economic losses for all similar objects of the street and road network, then the annual amount can reach 2–3 % of the city budget (about 2 million conventional monetary units per year). Thus, it is necessary to strive to reduce vehicle delays, increase the traffic capacity of road network facilities (in particular, regulated intersections), which will lead to an increase in traffic speed, a decrease in travel time, fuel consumption, gas pollution and noise.

Originality and practical value

It is important to note that although the method used to analyze the capacity of the selected object of the road network is not completely new, however, its application in the course of a comprehensive assessment of economic losses arising from delays on sections of the road network and their insufficient capacity allows the best not only to determine the emerging economic losses, but also, as a consequence, on the basis of the results obtained, to determine the most promising ways to determine the capacity reserves and reduce economic losses. The use of this method on real objects of the road network allows developing the scientific interpretation of the methods used and expanding the scope of their application.

Conclusions

In conclusion, it should be noted that the main possibilities for reducing delays and the corresponding loss of time (and, as a result, economic losses) can be called the use of a number of measures associated with changing the structure of

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the traffic light cycle. Since at the intersection under study, in direction A, the two middle lanes are considered more loaded, it is proposed to optimize the traffic light cycle at this intersection.

The regulation cycle is 86 s, the duration of the green signal for pedestrians is 40 s. After the optimization of the traffic light cycle (namely, changing the duration of the green signal for pedestrians,

taking into account the equipment with a safety island) using a specialized software product, pedestrian delays slightly increased, however, transport delays in the two middle lanes decreased by 3 seconds. In addition, this will also lead to a reduction in cases of violation of road traffic rules by pedestrians (namely, crossing a passing part at a prohibiting traffic light).

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Визначення резервів зниження затримок і збільшення пропускної здатності вулично-дорожньої мережі м. Гомель як фактор скорочення збитків в дорожньому русі

Мета. Часто наявний рівень пропускної здатності об'єктів вулично-дорожньої мережі у великих містах буває недостатнім. Це пов'язано передусім із тим, що зростання міст значно випереджає реконструкцію й оновлення відповідної інфраструктури. Як наслідок, на міських дорогах виникають затримки руху різного характеру, супроводжувані економічними збитками. Тому пошук резервів для зниження різного роду збитків, пов'язаних із недостатньою пропускною здатністю вулично-дорожньої мережі під час організації міського дорожнього руху, є метою цієї роботи. **Методика.** Для визначення резервів збільшення пропускної здатності вулично-дорожньої мережі та зменшення різного роду затримок застосовано методику детермінованого аналізу, методику розрахунку циклу за Ф. Вебстером, засновану на використанні фазових коефіцієнтів і втраченого в циклі часу (як суму перехідних інтервалів), методику вимірювання інтенсивності руху автомобілів у транспортному потоці, а також методику розрахунку економічних збитків, що виникають у разі затримки руху транспортних засобів. **Результати.** Проведено дослідження затримок руху та витрат часу й відповідних їм економічних збитків, характерних для типових об'єктів вулично-дорожньої мережі міста (регульованих перехресть). Визначено резерви їх зниження і, як наслідок, збільшення пропускної здатності як окремих перегонів, так і в цілому вулично-дорожньої мережі міста. **Наукова новизна.** Застосування зазначеного методу на реальних об'єктах вулично-дорожньої мережі дозволило розвинути наукове інтерпретування використовуваних методик і розширити їх сферу. **Практична значимість.** Оцінка наявних проблем пропускної здатності й супутніх збитків дозволяє визначити найбільш перспективні резерви збільшення пропускної здатності і, як наслідок, зниження економічних збитків.

Ключові слова: пропускна здатність; вулично-дорожня мережа; аварійні втрати; економічні втрати; інфраструктура; дорожній рух

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