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MEASURES TO OPTIMIZE ROAD TRAFFIC AND CALCULATIONS OF ENVIRONMENTAL SAFETY AT SOME PROBLEM SECTIONS OF ROAD-ON-DON ROAD INFRASTRUCTURE

Durov R. S.[1], Varnakova E. V.[1],
Kobzev K. O[1]., Kobzeva N. D[2]
[1]Don state technical university, Rostov-on-Don, Russian Federation
[2]Rostov State Medical University, Rostov-on-Don, Russian Federation

roma.0107@mail.ru
katya-arena97@mail.ru
5976765@mail.ru
5976765@mail.ru

The article discusses the problem areas of the Combine Builders Square in Rostov-on-Don and possible measures that could improve traffic at this roundabout. Environmental indicators were calculated after carrying out the proposed measures to reduce CO emissions by cars. A comparative analysis of indicators before and after the events. The data obtained made it possible to establish how much the proposed measures to optimize traffic will help to reduce CO emissions by cars.

Keywords: car traffic, optimization of traffic, environmental safety, mass consumption of CO.

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МЕРОПРИЯТИЯ ПО ОПТИМИЗАЦИИ ДОРОЖНОГО ДВИЖЕНИЯ И РАСЧЕТЫ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ НА НЕКОТОРЫХ ПРОБЛЕМНЫХ УЧАСТКАХ ДОРОЖНОЙ ИНФРА СТРУКТУРЫ РОСТОВА-НА-ДОНУ

Дуров Р. С.[1], Варнакова Е. В.[1],
Кобзев К. О.[1], Кобзева Н. Д[2].
[1]Донской государственный технический университет, Ростов-на-Дону, Российская Федерация
[2]Ростовский государственный медицинский университет, Ростов-на-Дону, Российская Федерация
roma.0107@mail.ru
katya-arena97@mail.ru
5976765@mail.ru
5976765@mail.ru

В статье рассмотрены проблемные с точки зрения автомобильного трафика участки площади Комбайностроителей в Ростов-на-Дону и возможные мероприятия, которые могли бы улучшить ситуацию на этой развязке. Рассчитаны экологические показатели после проведения предложенных мероприятий по снижению выбросов СО автомобилями. Выполнен сравнительный анализ показателей до и после мероприятий. Полученные данные позволили установить, на сколько предложенные меры по оптимизации дорожного движения помогут снизить выбросы СО автомобилями.

Ключевые слова: автомобильный трафик, оптимизация дорожного движения, экологическая безопасность, массовый расход СО.

Introduction. The study of traffic on Kombaynostroiteley Square near the recreation center "Rostselmash" in Rostov-on-Don showed that the traffic flow at this interchange could be optimized.

There are three especially problematic areas in the specified territory:

— pedestrian crossing in front of traffic lights on Selmash Avenue, before entering the ring (Kombaynostroiteley Square);

— pedestrian crossing on Selivanova street after the exit from Kombaynostroiteley Square;

— the section from the exit from Kombaynostroiteley Square to Vilnyusskaya street (on the 1st Konnoy Armii) [1].

Main part

Measures to optimize road traffic in problem areas. The installation of traffic lights before entering the ring seems irrational. Traffic lights slow down traffic and create congestion on the roads. It is necessary to remove the traffic light and move the pedestrian crossing 50 m deep (towards the suburban bus station) [2]. Before the crossing, warning sign 5.19.1 "Pedestrian crossing" should be installed. Additional signs are not needed before the ring itself, since there are already signs: 2.4 "Give way" and 4.3 "Roundabout" [3].

It is also worth moving the pedestrian crossing 50 m deep on Selivanova street, further from the ring. At the entrance to Selivanova street from Kombaynostroiteley Square, drivers see sign 5.19.1 "Pedestrian crossing", which is less than 5 meters away from the roundabout. Because of this, vehicles stop to let pedestrians pass and form a traffic jam. With heavy traffic in rush hour, not less than 3-4 cars stop to let one pedestrian pass, which block two lanes on the ring area of Kombaynostroiteley Square. If the pedestrian crossing is moved deeper, the situation will change for the better, besides, all State standards and regulations will be observed [4].

Traffic on the 1st Konnoy Armii is one-way, two-lane. The lanes are wider than usual, so there is a possibility of trouble-free travel of three vehicles at once. However, a large number of cars are parked on both sides of the road, and this significantly reduces the capacity of the highway [5].

The traffic jam can start at this point, and end only after crossing on Vera Panova street. To improve the situation, it is necessary to prohibit parking from Kombaynostroiteley Square to Vilnyusskaya street (because after it the market parking begins). This section should be provided with signs: 5.27 "Parking restricted area"; 5.28 "End of Parking restricted area" and 8.5.4 "Duration" (7:00-19:00). This will significantly relieve the roadbed and increase the capacity of the road section [6].

Environmental safety calculations. Thanks to traffic optimization measures, traffic flow has increased from 10 km/h (2.78 m/s) to 20 km/h (5.56 m/s).

To determine the environmental impact of the activities carried out at the site under study, we compare the carbon monoxide (CO) emissions of passenger vehicles (V) with gasoline (forced ignition) and diesel engines. The calculation is carried out using methodological guidelines [7].

Mass flow rate, g/s, of the *i*-th pollutant (P) by a single vehicle (V) is determined by the formula:

$$M_i = Q_{\text{or}} c_i,$$

where Q_{or} — the volume flow rate of exhaust gases (EG) of the engine of a single car, m^3/s; c_i — the concentration of the *i*-th harmful substance in the exhaust gases of a single car, g/m^3.

Let us calculate the volume flow of exhaust gases by the formula:

$$Q_{\text{or}} = 0,0007\text{v}^2 - 0,0256\text{v} + 0,3184,$$

where v is the average vehicle speed, m/s.

For passenger cars, it is determined by the formula:

$$\text{v} = 1,8665\text{v}_{\text{тп}},$$

where $\text{v}_{\text{тп}}$ is the speed of traffic flow, m/s.

Let us calculate the speed of passenger vehicles before and after the optimization of traffic on the intersection [8]. Before optimization:

$$\text{v} = 1,8665 \cdot 2,78 = 5,19 \text{ m/s};$$

after optimization:

$$\text{v} = 1,8665 \cdot 5,56 = 10,38 \text{ m/s}.$$

Volumetric flow rate of passenger vehicles exhaust gases in the traffic flow before traffic optimization:

$$Q_{\text{ог}} = 0,0007 \cdot 5,19^2 - 0,0256 \cdot 5,19 + 0,3184 = 0,204 \text{ m}^3\text{/s};$$

after optimization:

$$Q_{\text{ог}} = 0,0007 \cdot 10,38^2 - 0,0256 \cdot 10,38 + 0,3184 = 0,128 \text{ m}^3\text{/s}.$$

The concentration of CO in the exhaust gases of a car can be represented as an analytical dependence:

$$c_i = f(\bar{\alpha}),\ c_i = f(\bar{N}),$$

where $\bar{\alpha}$ — the relative coefficient of excess air; $\bar{N}$ — the relative power of the engine (table 1).

Table 1

Analytical dependences of CO concentration in exhaust gas on $\bar{\alpha}$

Engine type	Range of variation $\bar{\alpha}$	Concentration, c_i, g/m^3
Petrol with forced ignition	0–1,0	$-237,71\bar{\alpha}^3 + 540,29\bar{\alpha}^2 - 385,24\bar{\alpha} + 92,937$
With compression ignition	0–1,0	$5,6754\bar{N}^4 - 11,758\bar{N}^3 + 9,9078\bar{N}^2 - 3,5046\bar{N} + 0,7996$

The relative excess air ratio for passenger cars with gasoline (carburetor) engines is calculated by the formula:

$$\bar{\alpha} = 0,8775\bar{N}^3 - 2,1263\bar{N}^2 + 2,0224\bar{N} + 0,2387.$$

The relative power of the engine is determined from the equation:

$$\bar{N}N_{\text{ном}} = \frac{\left[k_{\text{ф}}\rho_{\text{в}}F_s v_j^2 + mg\cos\gamma\left(f \pm \text{tg}\gamma\right) \pm \delta_{\text{вр}}am\right]v_j}{\eta_{\text{тр}}}.$$

Here $\bar{N}N_{\text{ном}}$ — the product representing the effective engine power; $N_{\text{ном}}$ — engine rated brake power, W (for passenger gasoline vehicles we assume = 60 000 W; for diesel- = 70 000 W); $k_{\text{ф}}$ — wind shape coefficient (for passenger vehicles = 0.15); $\rho_{\text{в}}$ — - air density, $\rho_{\text{в}}$ = 1.293 kg/m^3; F_s — frontal area of vehicle, m^2 (for passenger vehicles = 1.5 m^2); m — mass of vehicle, kg (for vehicles we assume m = 1750 kg), g — is the gravitational acceleration, m/s^2; f — is the rolling resistance coefficient, f = 0,02; $\delta_{\text{вр}}$ — the coefficient accounting for rotating mass; a — vehicle acceleration, m/s; $\eta_{\text{тр}}$ — the mechanical efficiency of the transmission.

A minus sign in front of $\text{tg}\gamma$ is put when driving downhill. For the estimated calculation, we take $\gamma = 0$.

The product $\delta_{вр}a$ for passenger vehicles can be represented by the expression:

$$\pm\delta_{\text{вр}}a = g\left(2,023v^{-1,0678} - \Psi\right).$$

here Ψ — is the coefficient of reduced road resistance. Numerically it is possible to specify $\Psi = (f \pm \text{tg}\gamma)\cos\gamma$.

Before optimization:

$$\delta_{\text{вр}}a = 9,87 \cdot \left(2,023 \cdot 5,19^{-1,0678} - 0,02\right) = 3,243;$$

after optimization:

$$\delta_{вр}a = 9,87\cdot\left(2,023\cdot 10,38^{-1,0678} - 0,02\right) = 1,444 .$$

Let us calculate the mechanical efficiency:

— for petrol engines with forced ignition

$$\eta_{тр} = -2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299 ;$$

— for compression ignition engines

$$\eta_{тр} = -1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755 .$$

So, substituting all known values into the equation, we get $\bar{N}$ of a passenger gasoline (carburetor) car before optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 5,19^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 3,243\cdot 1750\right]\cdot 5,19}{60000(-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299)},$$

$$\bar{N} = \frac{0,5215}{-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299} .$$

Hence:

$$-2,9224\bar{N}^4 + 3,4211\bar{N}^3 - 1,0995\bar{N}^2 + 1,0299\bar{N} - 0,5215 = 0 .$$

This equation has two real roots ($\bar{N}_1$ = 0,959 and $\bar{N}_2$ = 0,536), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume that at given speeds the achievement of such a relative power is hardly possible and the most likely solution is the second real root ($\bar{N}_2$) [9]. Thus,

$$\bar{N} = \bar{N}_2 = 0,536.$$

After optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 10,38^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 1,444\cdot 1750\right]\cdot 10,38}{60000(-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299)},$$

$$\bar{N} = \frac{0,5024}{-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299} .$$

Hence:

$$-2,9224\bar{N}^4 + 3,4211\bar{N}^3 - 1,0995\bar{N}^2 + 1,0299\bar{N} - 0,5024 = 0 .$$

The equation has two real roots ($\bar{N}_1$ = 0,969 and $\bar{N}_2$ = 0,517), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N} = \bar{N}_2$ = 0,517.

$\bar{N}$ of a passenger diesel car before optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 5,19^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 3,243\cdot 1750\right]\cdot 5,19}{70000(-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755)},$$

$$\bar{N} = \frac{0,447}{-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755} .$$

Hence:

$$-1,3238\bar{N}^4 + 1,118\bar{N}^3 - 0,031\bar{N}^2 + 0,8755\bar{N} - 0,447 = 0 .$$

The equation has two real roots ($\bar{N}_1$ = 1,11 and $\bar{N}_2$ = 0,461), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N} = \bar{N}_2$ = 0,461.

After optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 10,38^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 1,444\cdot 1750\right]\cdot 10,38}{70000(-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755)},$$

$$\bar{N} = \frac{0,4306}{-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755}.$$

Hence:

$$-1,3238\bar{N}^4 + 1,118\bar{N}^3 - 0,031\bar{N}^2 + 0,8755\bar{N} - 0,4306 = 0.$$

The equation has two real roots ($\bar{N}_1$ = 1,12 and $\bar{N}_2$ = 0,446), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N} = \bar{N}_2$ = 0,446.

Let us calculate the excess air ratio for a passenger vehicle with petrol engine.

Before optimization:

$$\bar{\alpha} = 0,8775\cdot 0,536^3 - 2,1263\cdot 0,536^2 + 2,0224\cdot 0,536 + 0,2387 = 0,847.$$

After optimization:

$$\bar{\alpha} = 0,8775\cdot 0,517^3 - 2,1263\cdot 0,517^2 + 2,0224\cdot 0,517 + 0,2387 = 0,837.$$

We determine the concentration of CO in the exhaust gases of passenger vehicle by the formulas from table. 1.

Passenger petrol (carburetor) vehicle before optimization:

$$c = -237,71\cdot 0,847^3 + 540,29\cdot 0,847^2 - 385,24\cdot 0,847 + 92,937 = 9,804 \text{ g/m}^3;$$

after optimization:

$$c = -237,71\cdot 0,837^3 + 540,29\cdot 0,837^2 - 385,24\cdot 0,837 + 92,937 = 9,614 \text{ g/m}^3.$$

Passenger diesel vehicle before optimization:

$$c = 5,6754\cdot 0,461^4 - 11,758\cdot 0,461^3 + 9,9078\cdot 0,461^2 - 3,5046\cdot 0,461 + 0,7996 = 0,394 \text{ г/м}^3;$$

after optimization:

$$c = 5,6754\cdot 0,446^4 - 11,758\cdot 0,446^3 + 9,9078\cdot 0,446^2 - 3,5046\cdot 0,446 + 0,7996 = 0,389 \text{ г/м}^3.$$

Based on the data obtained, we find the mass flow rate of a single passenger vehicle.

Gasoline carburetor car before optimization:

$$M = 9,804\cdot 0,204 = 2,00002 \text{ g/s};$$

after optimization:

$$M = 9,614\cdot 0,128 = 1,2306 \text{ g/s}.$$

Diesel vehicle before optimization:

$$M = 0,394\cdot 0,204 = 0,0804 \text{ g/s};$$

after optimization:

$$M = 0,389\cdot 0,128 = 0,0498 \text{ g/s}.$$

The mass consumption of CO by passenger cars in the traffic flow on the part of the road network is determined by the formula:

$$\sum M_{ijk} = M_{ijk}\lambda_{jk}K,$$

where λ_{jk} — the share of cars by the purpose and type of fuel in the traffic flow (for gasoline passenger vehicles λ_{jk} = 0,36, for diesel vehicles — λ_{jk} = 0,014); K — traffic volume (the number of vehicles on the road transport network at the moment), pcs.

The volume of traffic is calculated by the formula:

$$K = \left[\frac{L - d_{\text{cp}}}{h} + 1\right] z,$$

where d_{cp} — the average length of the vehicle, m (we take 5.5 m for traffic flow); h — the average spatial interval between cars, m; z — the number of lanes (take z = 4).
Average space interval between cars:

$$h = 0{,}0285 v_{\text{т.п.}}{}^2 + 0{,}504 v_{\text{т.п.}} + 5{,}7\,.$$

Let us calculate the average spatial interval and the volume of movement (taking into account the increase in the length of the study area).

Before optimization:

$$h = 0{,}0285 \cdot 2{,}78^2 + 0{,}504 \cdot 2{,}78 + 5{,}7 = 7{,}32 \text{ m};$$

$$K = \left[\frac{200 - 5{,}5}{7{,}32} + 1\right] \cdot 4 = 110{,}3 \text{ pcs.};$$

after optimization:

$$h = 0{,}0285 \cdot 5{,}56^2 + 0{,}504 \cdot 5{,}56 + 5{,}7 = 9{,}38 \text{ m}$$

$$K = \left[\frac{360 - 5{,}5}{9{,}38} + 1\right] \cdot 4 = 155{,}2 \text{ pcs.}$$

Then the mass consumption of CO emissions by cars on the studied section of the road network before optimization is:

$$M = 110{,}3 \cdot (2{,}00002 \cdot 0{,}36 + 0{,}0804 \cdot 0{,}014) = 79{,}5412 \text{ g/s};$$

after optimization:

$$M = 155{,}2 \cdot (1{,}2306 \cdot 0{,}36 + 0{,}0498 \cdot 0{,}014) = 68{,}8642 \text{ g/s}.$$

As a result of the optimization, the time of movement of passenger vehicles on the section has changed.

Before optimization:

$$t = \frac{200}{5{,}19} = 38{,}54 \text{ c};$$

after optimization:

$$t = \frac{360}{10{,}38} = 34{,}68 \text{ c}.$$

Thus, the total emission by cars during the movement in the section before the optimization amounted to:

$$M = 79{,}5412 \cdot 38{,}54 = 3065{,}518 \text{ г} = 3{,}066 \text{ kg};$$

after optimization:

$$M = 68{,}8642 \cdot 34{,}68 = 2388{,}21 \text{ г} = 2{,}388 \text{ kg}.$$

Conclusion. Thus, the implementation of measures to optimize the road traffic will reduce emissions from cars by about 22 %, which will lead to a significant improvement in the quality of atmospheric air in the study area [10].

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Autors:

Durov Roman Sergeevich,
Undergraduate, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, Russia), roma.0107@mail.ru

Varnakova Ekaterina Vladimirovna,
Undergraduate, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, Russia), katya-arena97@mail.ru

Kobzev Kirill Olegovich,
associate professor of the Transport Systems Operation and Logistics Department, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, Russia), candidate of technical sciences,
5976765@mail.ru

Kobzeva Nataliya Dmitrievna,
assistent ,the Department of Internal Medicine No. Rostov State Medical University (29, Nakhichevanskiy ln., Rostov-on-Don, 344022, Russia), candidate of medical sciences,
5976765@mail.ru