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SCHEDULING ROAD TRAFFIC LIGHT TO CONTROL THE EMISSION OF CARS EXHAUST GASES[*]

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Abstract

The increase of the number of cars is an objective social process. The constant increase in the number of cars complicates the environmental situation in large cities and megacities. Road transport is one of the main sources of air pollution. The formation of toxic substances from cars exhausts is closely related to the processes of fuel oxidation and engine operating modes, which depend on the mode of movement of cars. The aim of this study is to reduce vehicle exhaust emissions through adaptive traffic light control. An analysis of the influence of the used method of controlling traffic signals on the level of emission of exhaust gases of cars was carried out using the constructed microscopic simulation model. The use of pre-calculated control and adaptive traffic light control was compared, taking into account the dynamics of transport demand. The conditions are identified under which the use of adaptive control of traffic signals can significantly reduce the volume of emission of exhaust gases of cars.

Keywords: adaptive control, pre-calculated control, reduction of emissions, safety, transportation, traffic, traffic light control

1. Introduction

Road transport for most countries is the main mode of inland transport. Cars are a key element of the transport system, which plays a major role in ensuring economic growth and social development. This was facilitated by its objective advantages, complemented by significant progress in the field of road construction and vehicle structures. Cars are also characterized by the widespread adoption of industrial and transport policy systems.

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The process of increasing the number of cars has a number of negative aspects in the field of road safety, the environment and the consumption of natural resources. Road transport has become one of the main sources of atmospheric pollution (Isaeva, 2017). Its share in atmospheric pollution in megacities is 70-80 % of the total emissions of substances into the atmosphere. Air pollution has harmful effects on humans, animals and the environment. Reducing the volume of emissions of toxic components of exhaust gases and reducing the environmental burden on the environment from road transport is one of the most important problems on the planet.

The formation of toxic substances in the exhaust gases of the car is the product of incomplete combustion of fuel and the formation of nitrogen oxides (NOx) in the combustion chamber of the car engine. The process of formation of toxic components is quite complex and can go along two fundamentally different paths. The first group of toxic substances is associated with chemical reactions of fuel oxidation that occur both during the pre - flame period and during the combustion-expansion process. The second group of toxic substances is formed when nitrogen and excess oxygen are combined in the combustion products (Skryabin, 2015). The nature of the engine operation, and accordingly the composition of exhaust gases released into the environment depends on the mode of movement of the car. In places where traffic is difficult, exhaust gas emissions are significantly higher. In the idle mode, and especially the speed set, the maximum volumes of exhaust gases are released into the atmosphere.

Main objective of this research is decrease in emission of exhaust gases of cars.

The purpose of the study is to analyze the effect of using various traffic light control methods on exhaust gas emissions and the noise level created when driving cars. The research is based on the results of practical research and a simulation model of car traffic. The application of two scenarios for traffic signal control is considered: the basic control scenario based on the use of local pre-calculated signal plans; local adaptive traffic signal control.

This work includes three main parts:

- selection of objects for experiments: a street with a large volume of transit traffic in the city of Penza of the Russian Federation was selected. Conducting practical researches of street characteristics and traffic flow intensity;
- development of a microscopic simulation model and options for monitoring traffic signals. Estimation of exhaust gas emissions and vehicle noise levels based on microscopic modeling;
- analysis of simulation results, forming conclusions and recommendations on the use of traffic light control methods.

2. Materials and methods

Transport flows have a number of properties that require the use of mathematical models in both research and practice:

- it is not possible to conduct practical experiments with traffic flows and networks for economic and security reasons;
- it is not possible to measure traffic flow parameters on the entire transport network.

The behavior of drivers and the nature of acceleration in the mode of following the leader has been widely studied since the 1950s. These models operate with such microscopic data as the speed of the driven car and its leader, the distance between them, and the acceleration of the driven car. Researchers began to pay attention to the behavior of drivers when accelerating in free flow mode in the early 1980s. At this time, microscopic modeling is an important tool in the study of traffic flows, driver behavior, and the development and evaluation of various management strategies and control in traffic.

Microscopic modeling is currently the most accurate tool for evaluating decisions on the development of a transport system or traffic signal management system. For various traffic options, microscopic models determine the behavior of the traffic flow, describing the interaction between individual vehicles based on it. Both proprietary software for microscopic traffic modeling (AIMSUN, VISSIM, CORSIM, etc.) and free software (MITSIM, SUMO) are known.

SUMO (Simulation of Urban Mobility) (Eclipse SUMO, 2020) is the best solution for our research tasks. This microscopic simulation program is licensed under EPL 2.0 and is open source software (Krajzewicz et al., 2012). The main goal of SUMO is to provide the research community with a tool for implementing and evaluating traffic light control algorithms or approaches to traffic management (Eclipse SUMO, 2020).

Microscopic modeling includes three stages: preparation of the transport network, transport demand, and modeling options; actual simulation; and reporting and processing of results.

To carry out modeling and study the influence of traffic light control on exhaust gas emissions, the intersection of the Izmailov main street and the local Strelbischenskaya street in the eastern part of the city of Penza was chosen (Fig. 1).

For the correct creation of the model, the transport network and geographic subbase are converted from Open Street Map maps (Fig. 2). Based on the conducted field studies using the NetEdit tool, the number of lanes and the permitted directions of movement are determined.

The traffic signal switching scheme provides for the passage of traffic flows in two transport phases; a dedicated pedestrian phase is provided for pedestrians to cross the roadway.

Creation of transport demand is based on practical research of traffic intensity. The study was carried out by video shooting with subsequent cameral processing of the captured material. The survey was carried out on a working day from 6:00 to 13:00 in increments of 1 hour (Fig. 3). The duration of the survey was 15 minutes.

Fig. 1. The intersection scheme with the number of directions

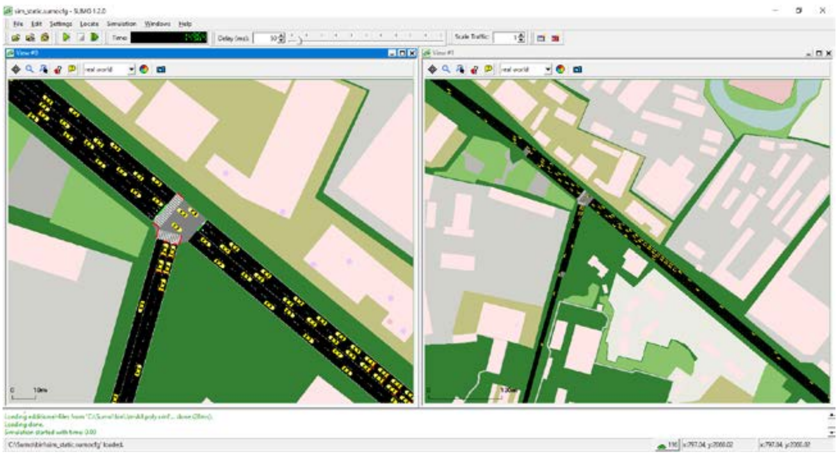

Fig. 2. Geo-SUMO intersection model with a geographical sub-base from OSM

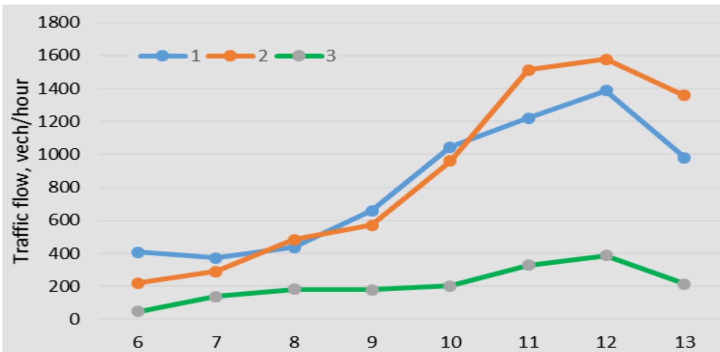

Fig. 3. Traffic intensity by direction of travel

In the research period, the maximum intensity of the traffic flow was recorded at 12 hours (noon) local time. This period was subsequently used as a settlement for the pre-calculated management. Passenger cars predominate in the transport stream (Fig. 4.), the share of trucks is 1% and buses are 4%.

SUMO allows you to objectively compare traffic light control options by using the same traffic demand for different control options. To perform the simulation, taking into account the composition of the traffic flow, the simulation scenario used transport demand for three categories, taking into account the ratios between cars, buses and trucks obtained in practical researches.

Pre-calculated control is used as the basic option for controlling a traffic light object. Optimization of the duration of the control cycle was performed in the Synchro 8.0 program for peak intensity obtained from practical researches.

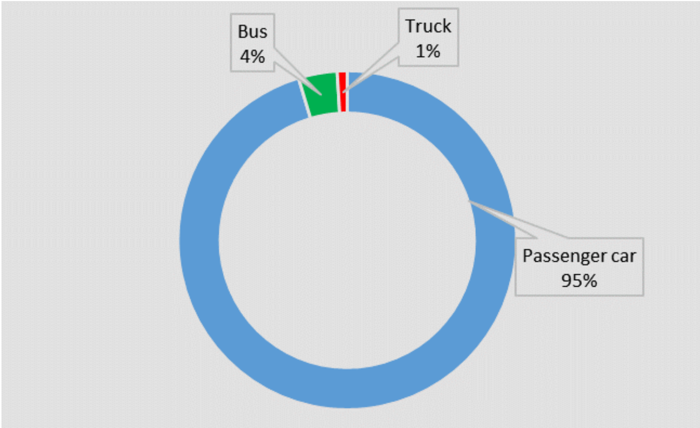

Fig. 4. The composition of the transport stream at maximum load

The duration of the regulatory cycle is determined by the formula:

$$T = \frac{1.5 \cdot \sum_J t_j + 5}{1 - \sum_N Y_n} \qquad (1)$$

where:
T –is the cycle duration, seconds;
$\sum_J t_j$ –the sum of all phases whose duration is fixed (transition cycles, pedestrian phases, etc.), $j \in J$;
Y_n–the phase coefficients of the transport phases, $n \in N$;
J–a set of phases whose duration is fixed;
N–set of transport phases, the duration of which is to be determined.

The phase coefficients Y_n are determined by the following procedure. The phase coefficients y_k for each group of lanes are determined using the formula:

$$y_k = \frac{q_k}{C_k} \qquad (2)$$

where:
q_k–traffic intensity for a group of lanes, cars per hour;
C_k–lane saturation flow k, cars per hour.

Determination of phase coefficients on the set $\hat{O}$ as follows:

$$Y_n = \max(y_m) \;\; m \in \hat{O} \wedge m \in n \qquad (3)$$

The duration of green signals for transport phases g_n is determined by the formula:

$$g_n = \frac{\left(T - \sum_J t_j\right) \cdot Y_n}{\sum_N Y_n} \qquad (4)$$

The optimal duration of the traffic light cycle was 80 seconds, including a dedicated pedestrian phase lasting 21 seconds. As an alternative option for controlling a traffic light object, an algorithm for searching for a gap in the flow was used (Traffic-Actuated Control). A detailed description of this control method can be found in the references (Gordon and Tighe, 2005).

3. Results and discussion

SUMO allows estimating the emission of toxic components of the exhaust gases CO, CO2, NOx, PMx and HC based on the HBEFA emission model adapted to the conditions of microscopic modeling (INFRAS Berne, 2020).

The results of microscopic modeling are available in saved xml files or transmitted through the socket connection of the TraCI module. The simulation results are presented both in aggregated form by the elements of the transport network, and in disaggregated form - the current state of the simulation objects (Krajzewicz et al., 2015). The following types of aggregated data are available to represent the transport network at the level of links and lanes:

- exhaust gas emission (edge / lane emissions): the aggregated value of exhaust gas emissions from vehicles over lanes / lanes;
- noise (edge / lane noise): noise from cars in communications / lanes.

Exhaust gas emissions are determined by the fuel consumption and environmental class of vehicles. The composition of the flow of cars and the prevailing environmental classes of cars in the short term is quite stable and is determined by the state policy in the field of environmental standards. At the same time, fuel consumption is a dynamic value and is determined by the vehicle's driving mode, which largely depends on the traffic control used (Fig. 5.).

Consider the dynamics of normalized CO emissions on the approach to the simulated intersection along Izmailova street (direction 1, fig. 1). During the simulation, three characteristic periods are distinguished (Fig. 6.). A period of low traffic. Deviations in the duration of the control cycle elements from the optimal ones do not significantly affect the performance indicators. Adaptive control has no advantage over pre-calculated control. Fuel consumption and exhaust emissions are similar for both control options.

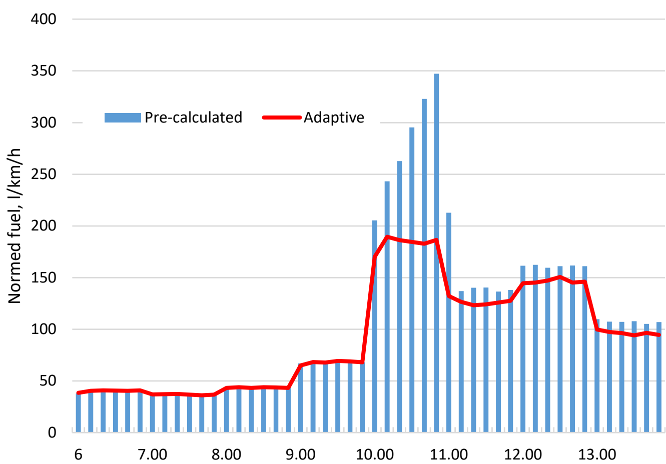

Fig. 5. Normalized fuel consumption

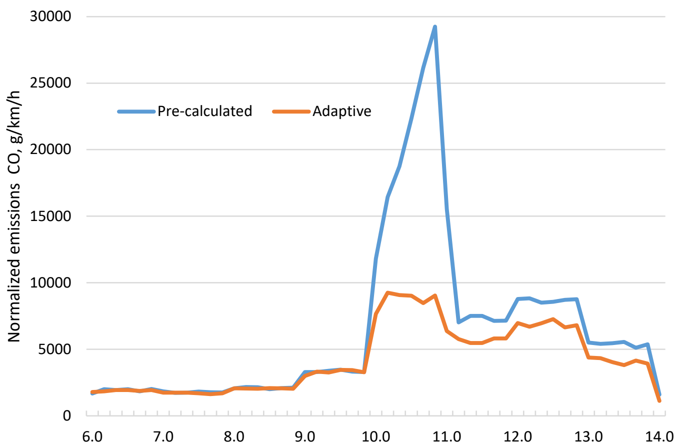

Fig. 6. Normalized emission of CO

The period of not effective pre-calculated control. Deviations in the duration of the control cycle elements from the optimal ones are significant and create prerequisites for the formation of traffic congestion, and as a result, a sharp increase in exhaust gas emissions. The use of adaptive regulation makes it possible to effectively compensate for the resulting changes in transport demand and the increase in normalized emission indicators is not as significant as with pre-calculated control.

The period of optimal pre-calculated control. The differences in exhaust emissions for pre-calculated and adaptive control are not as large as in the previous period, but are significant in order to make a choice in favor of adaptive control.

Considering the normalized emission for cars (Fig. 7.), we can note a fairly high stability of this indicator for adaptive control in comparison with the pre-calculated one. This phenomenon is probably explained by the ability of adaptive traffic light control logic to respond in a timely manner to fluctuations in transport demand and provide a higher level of service to traffic participants. For a relative assessment of the efficiency of using an alternative option for controlling traffic signals, we use the efficiency indicator *E*, calculated according to the following expression:

$$E = \frac{P_p - P_{Adaptive}}{p_P} \cdot 100 \qquad (5)$$

where P_p, $P_{adaptive}$ – values of the estimated parameter for pre-calculated and adaptive regulation.

The efficiency of using adaptive traffic light control largely depends on the intensity of traffic flow and the quality of the organization of work on managing the transport system (fig.8). If at low traffic intensity (up to 10 hours), the effectiveness of traffic control does not depend much on the preset mode of traffic lights or the use of adaptive control, then with its further increase, the differences become significant.

The period from 10 to 11 am is characterized by a significant non-optimality of the pre-calculated control of traffic signals. During this period, when using pre-calculated control, a residual queue is formed and traffic congestion develops. When using adaptive control, free driving conditions are maintained, so that the increase in exhaust gas emissions is not so large and is mainly associated with an increase in the number of cars that have passed. In the period from 11 o'clock, the pre-calculated control is quite close to the optimal one. Nevertheless, in the scenario with adaptive control, the emission of exhaust gases is on average 9-10% lower than in the pre-calculated control. Consider the relationship between the performance indicator and the relative lane loading (Fig. 9).

Let's note that high-quality change in traffic conditions occurs at a specific traffic intensity of 400-450 cars per hour per lane. This indicator can serve as a criterion that indicates the need for more careful planning of the calculation and updating of signal plans or the transition to adaptive control of traffic signals.

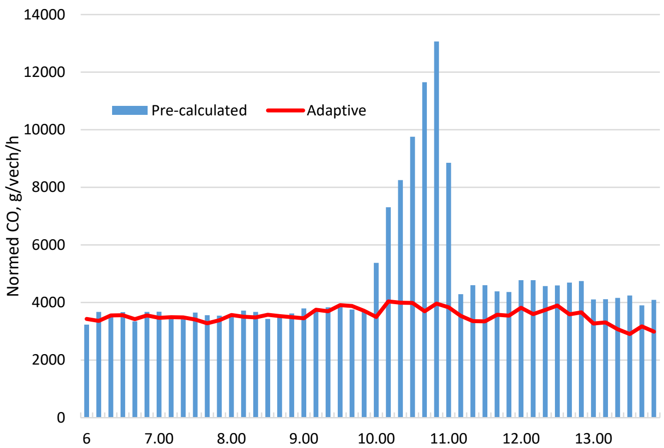

Fig. 7. Normalized CO emission by car

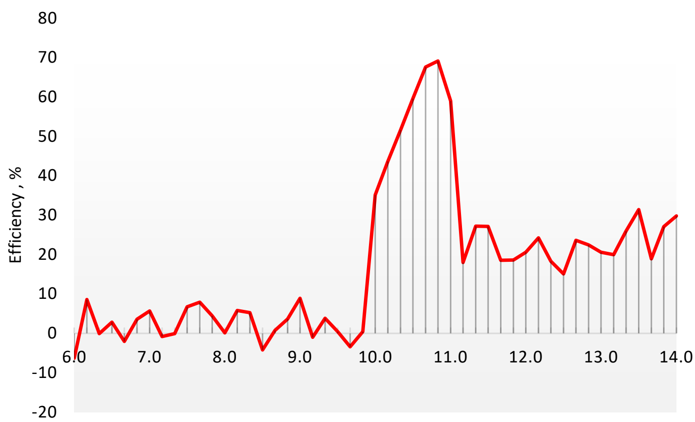

Fig. 8. The efficiency of adaptive regulation based on exhaust gas emission criteria

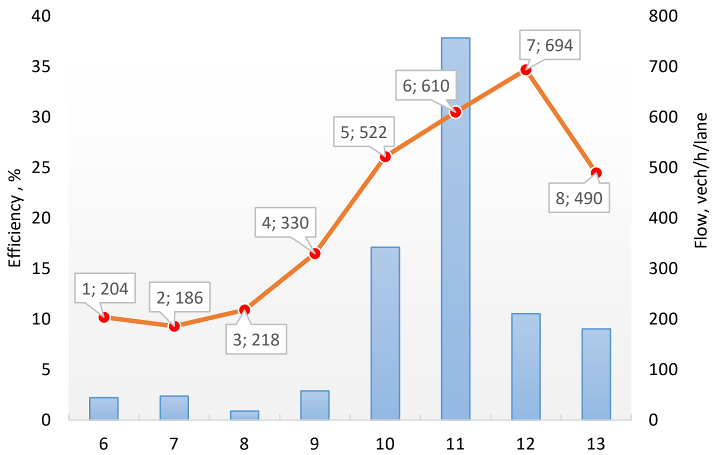

Fig. 9. The efficiency of adaptive control and the relative loading of traffic lanes

4. Conclusions

The effectiveness of adaptive traffic light control is determined by the intensity of traffic flow. When the traffic intensity is up to 300 cars per hour per lane, there is no significant effect from the use of adaptive control. If the traffic intensity exceeds the specified values, the significance of local fluctuations in transport demand increases. When the traffic flow is 400-800 cars per hour per lane, the use of adaptive control is preferable and allows you to reduce fuel consumption and exhaust gas emissions by 9-10%.

References

Eclipse SUMO, (2020), *Eclipse SUMO - Simulation of Urban MObility*, https://www.eclipse.org/sumo/.

Gordon R.L., Tighe W., (2005), *Traffic control systems handbook*, Technical report, Federal Highway Administartion, New York, NY, USA, On line at: https://ops.fhwa.dot.gov/publications/fhwahop06006/index.htm.

INFRAS Berne, (2020), *HBEFA - Handbook Emission Factors for Road Transport*, INFRAS, Bern, Switzerland, On line at: https://www.hbefa.net/e/index.html.

Isaeva E.I., (2017), *Improving the efficiency of car use, taking into account the likelihood of traffic congestion*, Thesis for a Doctor of philosophy degree (Ph.D.) in Technical Sciences, specialty 05.22.10 - Operation or road transport, (in Russian), Saratov State Technical University, Orel, Russia.

Krajzewicz D., Behrisch M., Wagner P., Luz R., Krumnow M., (2015), Second Generation of Pollutant Emission Models for SUMO, In *Modeling Mobility with Open Data, Lecture Notes in Mobility*, Behrisch M., Weber M. (Eds.), Springer International Publishing, Cham, Switzerland, 203-221.

Krajzewicz D., Erdmann J., Behrisch M., Bieker-Walz L., (2012), Recent Development and Applications of SUMO - Simulation of Urban MObility, *International Journal On Advances in Systems and Measurements*, **5**, 128-138.

Skryabin M.L., (2015), Influence of exhaust gases of automobile transport on the environment, (in Russian), *Young Scientist*, **13**, 185-187.