Assessment of Modern Technology Influence in the Transport Industry to Reduce Carbon Dioxide Emissions

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Abstract. The modern ecological direction of development of all industries leads to the creation and introduction of new technologies, in particular in the field of transport. At present, the introduction of wireless technologies as well as information and automated systems is observed in transport systems. This causes the creation of automated passenger cars. The article describes the analysis of previously completed studies that are aimed at creating models of logic and driver assistance systems. The results of researches, which were analyzed, showed that the implementation of fully automated systems in traffic conditions, where the largest share of cars is driven by people, is inefficient. Therefore, researchers consider connected systems, which include V2X technology. It includes the possibility of interaction between vehicles, its connection with the infrastructure, pedestrians and various devices. This eliminates the factor of “human error” in the case of driving a vehicle. In this study, an assessment of the impact of vehicle proportion, which is equipped a V2V system, and the maximum desired speed on the average delay time was carried out using simulation modeling. As a result, the authors found that an increase in the first factor, respectively, contributes to a decrease in the output indicator. The introduction of vehicles equipped with a V2V system reduces its fuel consumption and carbon dioxide emissions.

1. Introduction

At present, the introduction of technologies that are aimed at improving the environmental situation is a priority for the development of all branches in the Russian Federation. This is due to global processes that are associated with a reduction in harmful substance emissions into the atmosphere, in particular greenhouse gases. According to the forecasts of the International Energy Agency, the growth and maintenance of the existing state of harmful substance emissions into the atmosphere will lead to an increase in the global average temperature by more than 2°C by 2050, and consequently, to climate change and an increase in the number of natural disasters. At the same time, an unfavorable ecological situation also affects the health of the population and it causes an increase in the number of congenital diseases. This leads to the development of modern sustainable cities that have an ecologically friendly, safe and comfortable environment for living [1]. When the urban area is planned, industrial zones are moved to the boundaries of the area, freight traffic is limited, the use of alternative energy is considered for energy supply of objects, pedestrian zones that are free from cars, are allocated, electric transport and technologies associated with it are developed.

In the city, where there are no industrial centers, road transport is one of the largest sources of environmental pollution. In the Russian Federation for six years the amount of harmful substance emissions from cars increased by 14%. At the same time, during 2017 the increase is small and it amounts to 2.5%. Its total number is almost 14.5 million tons and varies depending on the substances contained in the exhaust gases of cars. For example, the amount of carbon monoxide, nitrogen dioxide,
sulfur dioxide, ammonia and carbon black increased by 9–16%, while methane decreased by half. The intensive growth of air pollution from road transport is due to an increase in the number of vehicles. So during the period under review, its number increased by 13%, and passenger cars increased by 15%. At the same time, only 13% of all considered vehicles complies with Euro-5 standards, and 54% are vehicles older than 10 years.

The development of the automotive industry, which is aimed at improving the environmental friendliness of vehicles, allows reducing emissions of harmful substances into the atmosphere. In the world at present, transport using alternative fuels, in particular electric energy, gas, and biofuel is actively developed [2,3]. According to the data of the international energy agency, the number of electric vehicles in the world exceeds 3 million, and by 2020 its number will be 13 million. In the Russian Federation, the development of these vehicles is considered to be 6-7 years behind the world processes. This is due to the lack of a developed charging infrastructure and services, as well as state support and incentives for citizens to buy environmentally friendly cars. However, the simultaneous development of driver assistance systems and vehicle interaction systems also have a significant impact on reducing emissions of harmful substances into the atmosphere by deciding on the optimal driving mode.

In the Russian Federation, at present, intensive growth of the vehicle fleet and the lack of advanced development of the road network cause an increase in vehicle delay time. Historical development of the territory with a street-road network, which has a low traffic capacity, and a large number of traffic lights are additional negative factors. In this case, the optimization of the traffic light cycle on intersections is considered as one of the methods for increasing the traffic capacity of the road network. At the same time, the capacity also depends on the delay time between turning on the green signal of the traffic light and the first car crossing the “stop line”, as well as on the distance between vehicles. The main characteristics of the behavior of drivers such as reaction time, prediction and concentration of attention affect the above indicators in the calculation of throughput. In this case, maintaining an equal distance between vehicles and the absence of a “human factor” allows increasing the crossing capacity [4]. Also, the introduction of vehicle interaction systems, both among themselves and with infrastructure, contributes to this. It covers almost all aspects of decision making by drivers and it helps make safe and reliable decisions in the shortest possible time.

Increased intersection capacity will reduce vehicle delay time as well as reduce vehicle travel time. It also contributes to the reduction of harmful substances total emissions into the atmosphere. Thus, the purpose of this article is to reduce emissions of harmful substances into the atmosphere with exhaust gases of vehicles while increasing the capacity of the road network by introducing vehicles equipped with systems of interaction between themselves and with the infrastructure.

2. Methodology

Modern cars are equipped with the vehicle to everything system, which includes several components, namely, the system of interaction between vehicles, with electronic devices, pedestrians, infrastructure. The implementation of these systems is aimed at helping the driver to make a decision, which leads to the replacement of the existing human driving logic with autonomous vehicles.

Initial models of decision-making processes when driving vehicles were considered taking into account acceleration behavior and using technologies such as adaptive cruise control [5,6]. Then the automated road system (this set of designated lanes along which autonomous vehicles move), where the possibility of controlling the flow and overloads was considered, was developed and modeled. The introduction of adaptive cruise control in this system and the structure of its modeling has been studied in the paper [7]. As a result of obtained data analysis, the conclusion was drawn that the workload of the automated road network is a function of the strategy for the movement of vehicles and the decisions made by the flow control center. Therefore, the use of macroscopic modeling and adaptive cruise control with the use of a neural network controller makes it possible to avoid congestion of the road network. Thus, these studies and the concept of an automated road system led to the creation of driver assistance systems.
Early versions of driver assistance systems used only on-board sensors and had the ability to adjust the vehicle speed based on data from the vehicle in front. However, during the development of the automotive industry, the observed introduction of wireless technologies leads to the improvement of existing systems. At present, vehicle interconnection technologies V2V and V2I infrastructure are developed. This allows you to create a system of interactive adaptive cruise control, which is able to automatically adjust the speed of the vehicle based on the data on the behavior of all vehicles in the stream (i.e., data from both the vehicle ahead and the following cars). For the first time, data management systems logic was proposed by Bart van Arem [8]. To make a decision, they used both the speed of the vehicle relative to the vehicle in front, and the deceleration, acceleration of flow and spacing. Later, the paper [9] proposed logic, which is obtained on the basis of a model for predicting the behavior of a stream, where each car uses information from the vehicle in front.

The modeling of these systems was studied by Zhao and Sun using the VISSIM software package [10]. In the course of this research, the influence of the group size and the share of vehicles with adaptive cruise control systems and the interacting adaptive cruise control on throughput were analyzed. As a result, an analysis of the study showed that an increase in the share of cars equipped with an interacting adaptive cruise control system causes an increase in throughput. However, according to the data presented in [11], the share of these vehicles is small and the speed of implementation is low. When these vehicles are in operation, the interacting cruise control assumes the presence and transmission of the required parameters of each vehicle moving in the stream. Therefore, at present, connected systems that can read and select motion signals embedded in its controller, based on a special V2X connection, are the most common. This leads to the possibility of effective use of vehicles with a plug-in system in a traffic flow, where cars are driven by people. [12]. The ability to reduce speed fluctuations, increase safety and fuel economy of cars by creating driving conditions with a minimum number of braking and acceleration in a stream of vehicles driven by people is an advantage of these systems.

The study of the influence of the behavior of people-driven vehicles on the performance of a connected vehicle with a V2X system in actual operating conditions is presented in the paper [13]. In the course of this study, an experiment was conducted to objectively evaluate data on a covered site and public roads. As a result, the connected cruise controller, which was able to receive information from vehicles that was not within the line of sight, was developed and experimentally tested. It was able to obtain information when the geometry of the road was difficult. At the same time, smoother braking and acceleration than with a automated system were observed in the case of operation of the connected vehicle system while driving. Thus, the authors confirmed the assumption that plug-in cruise control can have a positive impact on throughput, even in the absence of the formation of a traffic stream of automated cars. This prevents the formation of traffic jams. The effect of mixed traffic, which consisted of conventional vehicles and vehicles equipped with adaptive cruise control, on its stable was considered Bose and Ioannou [14]. They found that the introduction of vehicles with an adaptive cruise control system leads to an increase in driving stability, a reduction in emissions of harmful substances and an increase in fuel efficiency [15,16]. However, the influence of V2X connected systems in vehicles on the throughput of multi-lane roadways and, consequently, on the change in emissions of harmful substances in the case under consideration is not sufficiently studied at present.

2.1. Methodology of research

Evaluation of the impact of connected vehicles with V2V technology on the capacity of a multi-lane carriageway was performed using simulation modeling in the PTV Vissim 8.0 software package.

Modeling of traffic flows was carried out on the basis of data obtained in the morning, evening and daytime on weekdays, as well as on daytime weekends. Melnikaite street of Tyumen was the object of observation. This is a main street, which has 6 lanes for the movement of vehicles in total in cross section for both directions. In some parts of the street, oncoming flows are separated by a dividing strip of 5m in width. The width of the carriageway is 10.5 meters, and the length of the street exceeds 8km. Also, sections of highways that transport traffic to the modeling area were modeled. It was 6 major intersections. The collection of parameters (composition of traffic flow, traffic intensity in directions,
indicators of traffic light regulation, transport demand and intensity of pedestrian traffic) was made for each object of observation.

The collection of materials was carried out by means of video fixation, in particular: it was a continuous video filming in the period from 7:00 to 20:00 at the entrance of traffic flows to the simulation area; it was video shooting of traffic flows on the object under study from two points simultaneously; it was assessment of transport demand before the intersection with an interval of 2 cycles of traffic light regulation. As a result, simulation modeling made it possible to carry out calculations of the road traffic parameters at the objects in question, taking into account the share of vehicles being introduced with V2V technology. Modeling vehicle data was carried out by setting the driving style (which included the average distance when stopping the vehicle, the distance of visibility, the limit of rear visibility, acceptable deceleration, the factor for reducing the safety distance, cooperative change of lane, maximum deceleration for general braking, distance, the minimum speed in a straight line with heavy traffic, the time between the change of direction, the modes of operation of traffic lights and the rules of priority riding intersections). The obtained data allowed us to calculate the share of reducing the time delay of vehicles and reducing the amount of carbon dioxide emissions into the atmosphere when introducing vehicles with V2V technology.

3. Results and discussion

To create a behavior model for the vehicle ahead, which is typical for vehicles equipped with a V2V system, the parameters presented in Table 1 were set additionally in the program.

| Parameter | Parameter value |
|-----------|-----------------|
| Realizable distance between two vehicles at a stop, m | 2 |
| Acceleration of the vehicle during the beginning of the movement, m / s² | 2.7-3.0 |
| Visibility distance of 4 vehicles in front, m | 0-250 |
| Maximum deceleration when changing lanes, m / s² | 4 |
| Minimum lateral distance, m | 1 |
| Maximum desired speed, km / h | 40 - 70 |

The assessment of the impact of the share of vehicles equipped with a V2V system on the capacity of a section of the road network was considered for different values of the average speed of a traffic flow. Therefore, we set the maximum desired speed, which varied from 40 to 70 km / h. The choice of value limits is due to the speed limit of vehicles in populated areas according to the rules of the road, operating in the territory of the Russian Federation.

The average delay time of vehicles, which was estimated with an increase in the share of vehicles equipped with a V2V system, from 0 to 100%, was used as an indicator of throughput when the values of the maximum desired speed were 40, 50, 60 and 70 km / h.

The data obtained allowed us to estimate the effect of the proportion of increase in vehicles and the maximum desired flow rate on its average delay time.

The influence of the share of vehicles equipped with a V2V system in the flow on the average delay time at the maximum desired speed of 60 km / h is presented in Figure 1.
Figure 1. The dependence of the change in the average delay time of vehicles with an increase in the share of vehicles with the V2V system, when the maximum desired speed is 60 km/h.

In this case, an increase in the share of vehicles equipped with a V2V system in the stream leads to a decrease in the average delay time on the multi-lane carriageway by 34.4%. At the same time, when the share of the studied vehicles in the stream is up to 33%, the effect of its number on the average delay time is not observed. It is manifested at the maximum desired speed of 60 km/h. During the search for such dependencies for speeds of 40, 50 and 70 km/h, the decrease in the average delay time is observed even when the value is less than 33%. The effect of the maximum desired speed on the average delay time, when the share of vehicles equipped with a V2V system is 66%, is shown in Figure 2.

Figure 2. The dependence of the change in the average delay time of vehicles with an increase in the maximum desired speed, when the share of vehicles equipped with a V2V system is 66%.

When the maximum desired vehicle speed increases, an maximum point equal to the maximum value of the average delay time is observed. This value is observed when the maximum desired speed is 60 km/h. Deviation from this speed leads to a decrease in the average delay time by 15.1%.

The complex effect of the maximum desired speed and the share of vehicles equipped with a V2V system on the average delay time is presented in Figure 3.
Figure 3. The dependence of the change in the average delay time of vehicles with an increase in the share of vehicles equipped with a V2V system for various maximum desired speeds.

The increase in the share of vehicles equipped with the V2V system leads to a decrease in the average delay time of 34.0-39.7%, when the maximum desired speed is from 40 to 70 km / h. An increase in the desired speed leads to a decrease in the weight of the influence of the share of vehicles equipped with a V2V system. So when the maximum desired speed is 40 to 50 km / h, an increase in the argument leads to a decrease in the output indicator by 36.4-39.7%, and when this value is 70 km / h, it is 34.0%.

Reducing the time delay of vehicles will lead to a reduction in carbon dioxide emissions during downtime due to an increase in the average speed of the traffic flow. The data accepted for calculation are presented in table 2.

Table 2. Baseline data for calculating the reduction of harmful substance emissions from exhaust gases.

| Name of the indicator                                      | Value of the indicator |
|------------------------------------------------------------|------------------------|
| Fuel consumption of cars when idle, l / h                  | 0.9                    |
| Share of decrease in vehicle delay time when implementing a V2V system | 0.34 – 0.40           |
| Number of vehicles in the simulated area, units / h        | 14.392                 |

According to the presented source data, the introduction of vehicles equipped with a V2V system allows reducing the total fuel consumption by 4.403 l / h (3.346 kg / h), and consequently, carbon dioxide emissions are reduced by 10.489 kg / h. This causes the environmental friendliness of the introduction of modern technologies in transport, in particular, V2V systems.

4. Conclusions
The introduction of modern technologies in transport, in particular V2V systems, leads to a decrease in the time of vehicle delays and an increase in the speed of traffic. This helps to reduce fuel consumption and, consequently, decrease emissions of harmful substances and greenhouse gases, in particular, carbon dioxide.
Experimental studies, which were performed using the PTV Vissim 8.0, showed that an increase in the share of vehicles equipped with a V2V system leads to a decrease in the average delay time. Identification of the dependence of the complex effect of the maximum desired speed and the share of vehicles equipped with the V2V system showed that the greatest impact of the last input indicator is observed at low speeds, namely 40-50 km/h. Increasing the maximum desired speed reduces the impact of the share of vehicles equipped with a V2V system.

Analysis of the results and calculation of the amount of carbon dioxide showed that a reduction in fuel consumption of 4.403 l / h would lead to a reduction in carbon dioxide emissions of 10.489 kg / h in the case under consideration.

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