Modeling the Movement of Trucks in a Traffic Flow of High Density

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***Abstract*— When modeling the movement of vehicles to develop intelligent transport systems and solve the problems of optimizing traffic flows in most cases, the mean values of average speeds and parameters of acceleration and deceleration are used. Experimental studies have shown that the standardized data used to calibrate models are far from reality. In the case of high-density traffic (traffic difficulties, road accidents, "traffic jams"), the movement characteristics of different vehicles are quite different. Studies have shown that weather and road conditions have a particular effect on changes in vehicle traffic characteristics. This is especially true for the movement of medium- and heavy-duty trucks. Relative values of average speeds, acceleration and deceleration values with a distribution by type of transport, obtained as a result of practical research, allow to obtain greater reliability in modeling real traffic flows in intelligent transport ecosystems.**

Keywords*— *urban transport; transport mobility; telematic data; traffic flow modeling

I. Introduction

An explosive increase in the number of vehicles in operation around the world and the absence of alternatives to transporting passengers or goods by car in many cases leave no choice in addressing environmental security, reducing the carbon footprint and ensuring the sustainable development of urban agglomerations. The gradual transition to electric vehicles (EVs) in the last five years and the emergence of autonomous vehicles on public roads give hope that the above challenges can be met in the near future. However, as shown by the work of researchers [2, 8], the introduction of autonomous and environmentally friendly electric cars alone cannot guarantee a reduction in greenhouse gas emissions and ensure a reduction in the unit cost of transportation. In works [6,7] it is clearly shown that the greatest effect of using an electrified or hybrid drive vehicle is achieved exactly in conditions of relatively free movement in a laminar traffic flow of low density or when driving on highways, similar results of modeling fuel consumption were obtained for traditional vehicles [4]. At the same time, as shown by our previous study [5], in the case of high-density traffic (morning or evening rush hour, difficult traffic conditions) due to a sharp decrease in the average speed of traffic, specific energy consumption and specific CO_2 emissions per passenger are significantly increased, which is an unacceptable fact in the concept of sustainable development of modern transportation systems. As experimental studies have shown, one of the reasons for even more slow traffic is buses, trolleybuses, and trucks. In free-flow conditions in the city their average speed differs by about 25-35% from the average speed of passenger cars, primarily due to the need to enter the stopping points and secondly due to the lower intensity of acceleration when speeding up. However, in conditions of dense congested traffic during rush hour two more factors are added to this - the loss of time when returning from the stopping point to the lane occupied by cars moving slowly or standing, as well as a significant total deviation from the flow rate due to the lower intensity of the beginning of traffic. The latter factor is exacerbated by the high frequency of this mode in dense rush-hour traffic. Under these conditions, the difference in the average speed of buses and cars, as preliminary studies have shown, was up to 42% [5].

In this regard, trucks are similar to buses and trolleybuses in the first approximation of their driving parameters. However, despite the absence of the need to approach stopping points, in the case of trucks of categories N2 and N3 driving on city streets, their average speed is even lower than that of public transport. This is due to the large mass of the vehicles, and therefore the inertia, the requirements to ensure the safety of the cargo and the peculiarities of management. As a result, the index of "dynamic dimension" of such vehicles, which includes the actually occupied part of the road, taking into account the safety zone and the actually lost zone in conditions of the continuing movement of the car and its separation from the vehicle ahead can increase to catastrophic

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proportions. In conditions of dense traffic during rush hour, this makes the already difficult traffic situation even worse. Application of modern adaptive cruise control systems [3] is inconceivable without constructing functioning and accurate digital twins of vehicles, it requires accurate modeling of vehicle driving modes in various traffic, road and climatic conditions.

As part of modeling traffic flows, implementing innovative automated intelligent transport systems and modernizing the existing traffic patterns of major cities the methods of simulation of traffic (software environment Any Logic, PTV Vissim) are used. The standardized values of average vehicle speeds, decelerations and accelerations are used as basic parameters during initialization and subsequent calibration of the models, and, as a rule, they are taken from the sample of previous models. At best, the calibration is carried out for average speeds based on the processing of data from traffic detectors or traffic cameras in the case of relatively free movement of cars. As a result, there is a fairly significant deviation of the actual passage of cars through the projected areas compared to simulation data [10]. In rush hour traffic conditions, the obtained modes of traffic and regulation of traffic light objects simply do not work, because they are configured for completely different parameters relative to the laminar flow of cars. A sudden change in weather conditions (fog, heavy rain, snow, ice) leads to exactly the same results, either leading to reduced visibility or to a deterioration in traction with the road. The solution to such situations is the use of adaptive, dynamically changing intelligent traffic management systems. The use of Vehicular Ad hoc Networks (VANETs) to dynamically re-route traffic in the presence of traffic jams [1] requires actual calibration data to predict traffic flows on the streets, as well as vehicle traffic parameters to model optimal routes and traffic light control modes [11]. However, the operation of the latter systems also requires models of the vehicles moving in different traffic modes [9].

Consequently, to improve the efficiency of the implemented intelligent traffic control systems, it is necessary to obtain reliable calibration data on the movement of trucks in cramped traffic flow conditions, including under different climatic and weather conditions. The study of truck traffic in conditions of low wheel traction in winter as part of rush hour traffic is presented in this paper.

II. Methods

Experimental studies were conducted in February 2022 in the city of Vologda, Russia. The population of the city is 312,000 inhabitants, motorization - about 104,000 cars, the area of the city is 116 km^2. To control the traffic flow, we have chosen a 2.3 km route along the Chernyshevsky street, which connects a large residential area with the city center (Fig. 1).

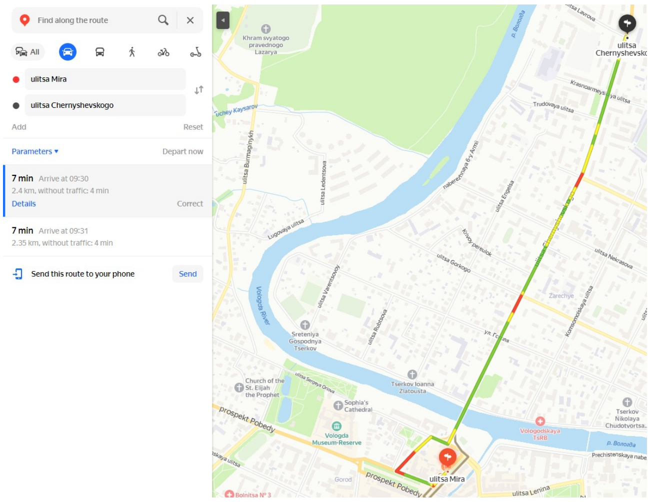

Fig. 1. Scheme of the route under study

At the same time this street is one of the entrance streets to the city, and up to the middle of the studied route the traffic of trucks of classes N2 and N3 is possible. The measurements were carried out in 2 stages. The 1st stage was conducted on weekdays during the inter-peak time from 2:00 p.m. to 3:00 p.m., the 2nd stage - during the evening rush hour from 5:30 p.m. to 6:30 p.m. The choice of time and measurement modes was also dictated by the presence of similar experimental data for September 2021 on this route [5], which made it possible to compare traffic modes, taking into account the presence or absence of snow cover on the road.

The duration of the data extraction was 5 days, Monday through Friday. Data on the traffic volume of cars, buses and trucks have been obtained using the intelligent object recognition system of the Intelligent Transportation System (ITS) currently being implemented in the city and data from the Yandex public transport tracking server, data on the number of public transport passengers using access terminals installed in buses. For trucks, the number of people in the cab was not determined.

The results of the study of traffic flow along the route and the average speed are shown in Tables I-II.

TABLE I. INTER-PEAK TRAFFIC DATA (WEEKDAYS BETWEEN 2:00 P.M. AND 3:00 P.M.)

Traffic participants	**Transportation performance**		
	Average quantity per hour	***Total number of passengers***	***Average speed, km/h***
Passenger cars	1526	1984	18
Buses	16	397	14
Trolleybuses	6	134	13
Trucks N2	18	-	17
Trucks N3	7	-	15
Total	1573	2515	-

TABLE II. RUSH HOUR TRAFFIC DATA (EVENING RUSH HOUR FROM 5:30 P.M. TO 6:30 P.M.)

Traffic participants	Transportation performance		
	Average quantity per hour	*Total number of passengers*	*Average speed, km/h*
Passenger cars	1105	1437	9
Buses	8	191	7
Trolleybuses	2	43	6
Trucks N2	15	-	6
Trucks N3	5	-	5
Total	1135	1671	-

The data indicated in Tables I-II on the occupancy of buses and trolley buses were calculated based on the received loading of vehicles (according to the processed results from ticket sales terminals), the occupancy of passenger cars was taken as 1.3 people in a passenger car according to visual observation data, as in the case of studies in September 2021.

Vehicle movement characteristics (average speed, acceleration and deceleration values) were obtained using Omnicomm Online real-time vehicle parameter telematics equipment for a number of 6 passenger cars, 4 trucks of category N2 and 3 vehicles of category N3, which passed along this route at the specified observation time. Due to the relative uniformity of traffic, their traffic indicators have been extended to other vehicles. The working screen of the telematic observation program is shown in Figure 2, and the calculated traffic parameters are shown in Tables III and IV.

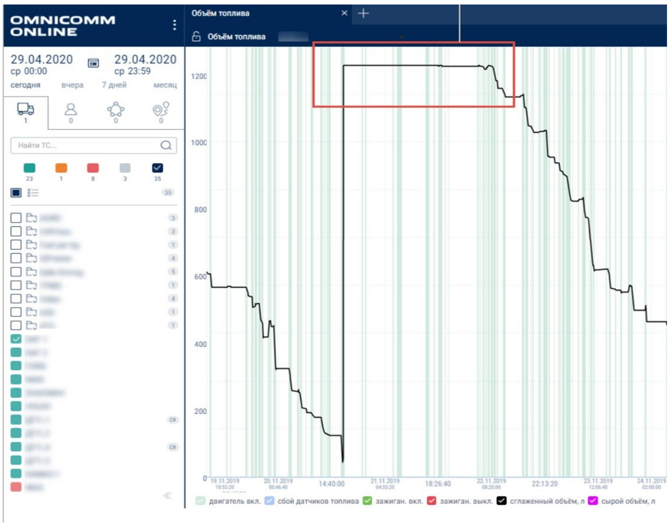

Fig. 2. Omnicomm program screen with the interim report of the truck movement

In the case of dense urban traffic, the value of the indicator L_d "dynamic vehicle dimension" (1), when using a safe distance between moving vehicles in the size of the overall length of the car, is determined as follows:

$$L_d = V \cdot T + V^2/(2J) + 2L_c,\ m \qquad (1)$$

where V is the speed of the vehicle, m/s;

T – driver reaction time, s;

J – deceleration under emergency braking, m/s^2;

L_c – vehicle length, m.

The results of calculating the indicators of "dynamic vehicle dimension" for both cases of movement along the analyzed route are shown in Tables III-IV. Vehicle lengths for the calculation are chosen according to the most common models.

TABLE III. ESTIMATED TIMES BETWEEN PEAK HOURS (WEEKDAYS FROM 2:00 P.M. TO 3:00 P.M.)

Traffic participants	Indicators calculated		
	Dynamic dimension of the participant L_d*, m*	*Average acceleration at starting off, m/s*^{2}	*Average deceleration during braking, m/s*^{2}
Passenger cars	13,17	1,04	4,4
Buses	27,32	0,88	3,8
Trolleybuses	26,99	0,93	3,9
Trucks N2	22,39	0,92	4,2
Trucks N3	39,01	0,85	3,5

TABLE IV. PEAK HOUR ESTIMATES (WEEKDAY EVENING RUSH HOUR FROM 5:30 P.M. TO 6:30 P.M.)

Traffic participants	Indicators calculated		
	Dynamic dimension of the participant L_d*, m*	*Average acceleration at starting off, m/s*^{2}	*Average deceleration during braking, m/s*^{2}
Passenger cars	10,94	0,86	3,7
Buses	25,51	0,72	3,1
Trolleybuses	25,23	0,76	2,9
Trucks N2	19,23	0,64	2,9
Trucks N3	35,97	0,57	2,6

In September 2021, similar tests were conducted on the same site [5], which allows us to compare the parameters of vehicle traffic under conditions of different pavement states. At that stage of experimental data collection, the average daily temperature was +9.9°C, rainfall averaged 2.2 mm per day. The temperature of the road surface was the average daily temperature of +10.8°C. The road surface was clean asphalt concrete. In the second phase of the study in February 2022, the average daily temperature was -3.5°C, precipitation in the form of snow averaged 1.5 mm per day. The average daily temperature of the road surface was -4.7 °C. The surface of the road - snow slush with road reagents.

III. Results

Application of the approach [5] made it possible to obtain the calculated characteristics of the dynamic dimensions of transport in urban traffic conditions under different traffic modes, road and weather conditions on the basis of experimental data obtained from the observation of heterogeneous traffic flow. The characteristics of the passenger flow on the studied route are shown in Table VI and Figures 2 and 3.

TABLE V. FLOW OF CARS ON THE STUDIED ROUTE IN %

Traffic participants	*% of the total volume during the off-peak period*	*% of the total volume in the rush hour*
Passenger cars	97,01	97,36
Buses	1,02	0,70
Trolleybuses	0,38	0,18
Trucks N2	1,14	1,32
Trucks N3	0,45	0,44
Total	100	100

Finding these values for the case of dense urban traffic in the rush hour allowed us to trace the dynamics of changes in these indicators with a sharp change in traffic modes - a drop in average speed and reduction of the distance to the nearest car. We can see that the share of passenger cars increases, while the share of trucks passing the specified route per hour decreases. Table VI shows the relative change in acceleration at starting and deceleration at service braking for the rush hour relative to free movement in the middle of the working day.

TABLE VI. RELATIVE CHANGE IN MOTION PARAMETERS

Traffic participants	***Relative change of acceleration value at starting off, m/s^2***	***Relative change of deceleration value during braking, m/s^2***
Passenger cars	-17%	-16%
Buses	-18%	-18%
Trolleybuses	-18%	-26%
Trucks N2	-30%	-31%
Trucks N3	-33%	-26%

From its data, it follows that the greatest decrease in acceleration and deceleration when driving in heavy traffic during rush hour is characteristic of trucks (up to 33%), while buses and trolley buses are almost the same as passenger cars (18 and 17% respectively). It is worth noting that along with the change in the mode of traffic (from relatively free movement to movement in dense traffic) the weather conditions have also changed. This primarily manifested itself in a sharp decrease in the coefficient of adhesion from 0.68-0.74 in the first phase of testing to 0.28-0.34 in the second due to negative temperatures and precipitation in the form of snow.

Figure 3 shows the relative change in the value of the dynamic vehicle dimension when driving between the rush hours and in the evening rush hour for different types of vehicles.

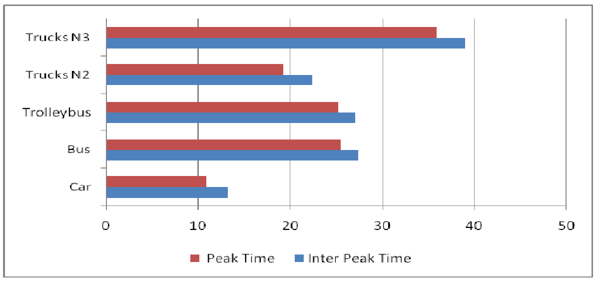

Fig. 3. Comparison of dynamic transport dimensions (m) in different flow modes

IV. Discussion

In terms of the index of dynamic vehicle dimensions, the movement of trucks in rush hour mode has a significant impact on their performance - a decrease in average speed, an increase in the number of acceleration-braking and increased fuel consumption. On the other hand, this transport is characterized by a sharp decrease in the acceleration value when starting from a place up to 33% relative to driving in less dense traffic. This fact leads to a noticeable increase in the distance to the vehicle ahead, and, taking into account the multiple cycles of "acceleration and deceleration", this leads to a significant stretching of the flow of cars and an even greater reduction in speed.

In our opinion, the available algorithms for control systems of adaptive cruise control of autonomous vehicles should be calibrated for the conditions of dense traffic in the direction of reducing the speed and decreasing the distance to the vehicle ahead. When operating in cold weather on slippery surfaces, these control systems should be calibrated taking into account the significant decrease in the tire traction coefficient and use algorithms preventing wheel slippage when starting off to compensate, at least in part, for the inevitable decrease in acceleration dynamics. This is the most effective solution for old large cities, which have an established street network and do not allow its expansion in order to reduce the flow of traffic and prevent the movement of heavy vehicles on the main urban traffic arteries.

Separately, it is worth noting the high values of the dynamic dimension of trucks, especially categories N3 against the values of passenger cars and buses and trolleybuses. On the other hand, when driving in dense traffic, a decisive role in this case is played by the cyclically formed gaps between the moving trucks with significantly reduced intensity of moving. It is this question that requires detailed research from the point of view of minimization of the phenomena mentioned above.

V. Conclusions

The hypothesis posed at the beginning of the experimental studies has been verified. Calculated data show that under conditions of simultaneous significant reduction in the coefficient of traction in winter slippery conditions and dense traffic, trucks lose significantly up to 33% in the intensity of acceleration. With the cyclic nature of this process, it leads to a significant reduction in the speed of both the trucks themselves and the traffic flow as a whole. This problem calls into question the further development of principles for organizing sustainable urban transport systems.

To solve this problem, it is necessary to change the transport systems in the existing urban agglomerations in a comprehensive manner, with a simultaneous implementation of a fairly strict administrative policy of restricting the passage of N2 and N3 trucks on intracity roads, the organization of special lanes for public transport and elimination of bottlenecks that lead to jams on the roads.

The results obtained on the changes in various modes of movement of the dynamic dimension of trucks and their driving parameters indicate the potential possibility of calibrating the algorithms of intelligent transport systems, traffic light facilities, including the modernization of existing road infrastructure [10-11].

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