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SIMULATION MODEL OF THE SPEED OF URBAN PUBLIC PASSENGER TRANSPORT ON ROUTES.

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Abstract This section outlines the principles for developing a simulation model of traffic flow to assess the speed of public transport, specifically buses, along a designated route. The model comprehensively accounts for factors affecting bus traffic: road conditions, traffic load levels, driver skills, vehicle design features, and traffic safety. In the study, a micro-level modeling approach was chosen, modeling the dynamics of interaction between free, partially coupled, and coupled vehicle modes, overtaking processes, and vehicles. Additionally, the structure of the model was developed based on the principle of aggregation, and the possibilities of describing traffic flows close to real conditions, predicting changes in bus speed, and assessing road safety were highlighted. The developed simulation model is recommended as an effective tool for analyzing traffic flows, optimizing traffic speeds, and solving scientific and practical problems in traffic management.

Keywords: simulation modeling, traffic flow, public transport, bus traffic, micro-level model, aggregation, traffic speed, traffic load level, free movement, partially connected traffic, overtaking, road conditions, transport safety, algorithmization, traffic flow management.

The development of simulation models for traffic flows is one of the most important and effective methods for studying the state of traffic organization. The adequacy of the developed model for a real transport flow, its volume, and complexity depend entirely on the task set for the modeling process. In the case under consideration, the task is to solve the problem of modeling the speed of buses traveling along designated routes under real traffic conditions based on parameters such as road conditions, the traffic load level of the street and road network, driver skill, and the structural features of the buses. In this case, the influence of factors influencing the change in movement speed in various situations, primarily the decrease in movement speed, was studied.

It is known that a bus moving along a route in a traffic flow is influenced by the level of traffic congestion of the street and road network; that is, as the level of congestion increases, the bus is forced to move in accordance with the speed of the traffic flow. The bus driver has the opportunity to independently choose the speed of movement only in a free mode, i.e., when $z \leq 0.2$. Starting from the moment when the traffic load coefficient of the street and road network is $z \geq 0.2$, a bus moving along a designated route in a traffic flow is forced to move depending on the speed of the vehicles in front of it. In this simulation model, the influence of traffic flow speed on directional movement speed is considered, i.e., its speed limitation. In this process, the primary focus is on the process of transitioning vehicles moving in a traffic flow from a free mode to a partially bound mode, as after $z \geq 0.45$, vehicles moving in the flow, including buses, will no longer have the opportunity to overtake them. Therefore, the speed of the bus moving along the route in the flow after it is carried out in the same order as the flow speed

A bus route with two traffic lanes and considering intersection traffic was selected as the structural component of the simulation modeling. The main reason for this is aimed at creating an opportunity to continue further research. Buses will operate along this route as part of the transport flow. Traffic safety was also selected as the desired spectrum that can be obtained from the characteristics of the simulation model; that is, ensuring the safety of a bus moving in a stream, including a route bus, was accepted as an integral part of the model. Therefore, the micro-level model

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was selected as the most widely used method of transport flow modeling. In this case, a bus traveling along the route was selected as the specific vehicle.

In this case, the aforementioned approach ensures not only the versatility of the developed model but also its simplicity for algorithmic development and programming. Furthermore, it allows for the economical and efficient use of software resources across a wide range of modeled movement modes.

It is known that in the study of complex systems, aggregates are often used as a mathematical scheme for the formal description of elements. Such an approach to modeling traffic flows involving a bus traveling along a route allows for the use of the developed aggregate for quantitative and qualitative analysis to investigate processes of various natures. In this model, the concept of an aggregate allows for describing the speed of a route bus at a specific location within the modeled street-road network. The developed model is interpreted as a system consisting of a set of final numbers with the interaction of piece aggregates.

The use of the aggregation principle in transport flow modeling has been reflected in a number of studies. At the same time, the entire process of the transport flow in the modeling section is covered as an aggregate.

The application of the concept of an aggregate to individual elements of road traffic, in our example, sets the following requirements for a bus moving along a route, which are set as a task to obtain the following characteristics necessary for the study:

-flexible to model control signals;

- universal in terms of task capability and range of input signal values;

- simple for algorithmization and programming;

- convenient for the possibility of automating the modeling of subsequent research processes.

The structure of the development of an imitation model system, i.e., the morphology of its organizational structure, is interpreted as follows. Two traffic flows are moving in opposite directions on a section of the road network with two traffic lanes. At each point of the simulated section, the traffic flow has its own independent distribution of free velocity $f_{free.}$ (v), which depends on given weather conditions, a combination of vehicle types, and various local traffic restrictions. The intervals between the appearance of new vehicles on the simulated section are independent random variables distributed according to a given law.

Each vehicle, in the absence of any external influence, has a given speed of movement at the input in accordance with the coordinate parameters of the law of free motion distribution. In this case, the speed of movement is assumed to be constant on the modeled section. On the modeled section, there is an intermediate distance between vehicles depending on the speed of movement.

The interaction between vehicles moving on the section under consideration is modeled using a simplified method of the dynamic theory of leader tracking. The transition from a free mode to a partially bound mode of movement occurs instantaneously. After this, the vehicle accelerates to the speed of the vehicle in front and moves in accordance with its speed while maintaining a sufficient clearance. In this case, the distance between the vehicles is maintained.

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If conditions arise in the traffic flow for overtaking, the following conditions must be met for its implementation:

- the ratio of the established criteria between the speeds of overtaking and overtaking vehicles should be sufficient to carry out an overtaking;

- overtaking on the section in question is not prohibited by traffic regulations;

- a sufficient interval between vehicles moving in opposite directions in the flow, corresponding to the specified intervals, to carry out an overtaking.

In order to simplify the step-by-step nature of the change in speed during the development of this simulation model, the car's speed during overtaking was adopted as a constant over the entire range as a criterion for overtaking. These restrictions apply equally to the overtaking vehicle and the vehicle being overtaken.

To analyze the critical moments of the recalculation of the modeled system, the method of recalculation over periodic intervals was selected. Let us consider the full operating algorithm of the model with an explanation of the formal presentation as a general system for generalizing units and units in a bus system moving along a modeled route.

A bus traveling along any modeled fixed route operates in three different modes, determining its position on the modeled section.When in a free-running mode (нус_N=1), the vehicle is assumed to move with an index N according to the coordinate of the parameters of the free speed distribution law assigned to it at the entrance to the modeled section, which is deemed acceptable by the driver of this vehicle. Local speed limits are taken into account. In a partially coupled mode of motion, the speed of the vehicle in question is equal to or less than the speed of the vehicle in front. In this case, it is assigned the index N-1. When moving in an overtaking mode, the speed of the vehicle is considered as a function of the speed of the vehicle moving in a free mode.

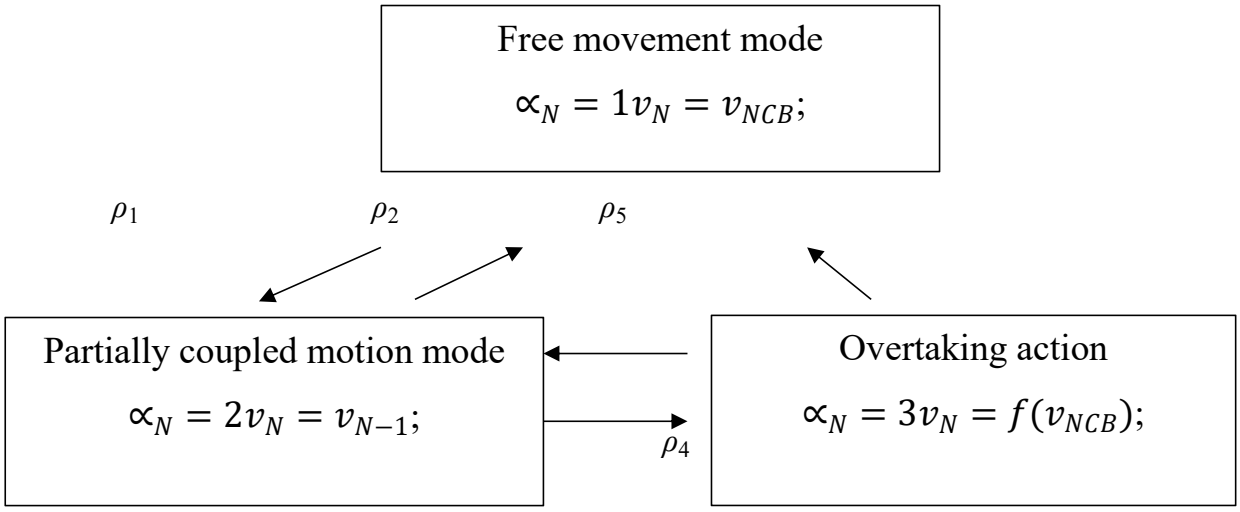


Figure 1. Graph position for a bus traveling in a simulated direction

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Let us consider the transition of a route bus moving in a stream from one mode of motion to another. For this purpose, we use the forms of indicative functions. In the process of transitioning from a free movement mode to a partially bound movement mode, the transition criterion is equivalent to the indicative function μ_1.

$$\mu_1^{\omega} \left(d_N \geq L_{N-1}^N\right) \vee \left(\left(\propto_N \& 3\right) \Rightarrow \left(d_N \geq L_{N-2}^N\right)\right), (1)$$

L_{N-1}^N, L_{N-2}^N Where Be, $d_N = D\ (v_N)$ - the dynamic dimension of the vehicle according to the velocity vector; - the distance between vehicles according to the corresponding index;

$\propto_N$ - the mode of movement of the vehicle according to the corresponding index.

The distance between vehicles in the order of free movement is as follows.

$L_{N-1}^N = a_{N-1} - a_N$, (2)

In a partially connected mode of motion, it can be seen as follows.

$L_{N-2}^N = a_{N-2} - a_N$, (3)

a_N where is the coordinate corresponding to the corresponding vehicle index.

$\mu_2^{\omega} \urcorner \mu_1$ The criterion for transitioning from a partially bound movement mode to a free movement mode, completing the overtaking, and transitioning to a free or partially bound movement mode, respectively, is expressed as follows:;

$$\mu_5^{\omega} \left(d_{N-1} < -L_{N-1}^N\right) \& \urcorner \left(d_N > L_{N-2}^N\right);$$

$$\mu_3^{\omega} \left(d_{N-1} < -L_{N-1}^N\right) \& \urcorner \left(d_N > L_{N-2}^N\right). (4)$$

$v_{N\,er.}(a) v_{chek}(a)$Let us consider the calculation of the speed of free movement. At each point of the modeled section, any ψ-vehicle with its own speed limitation is assigned parameters in accordance with the distribution law of free movement:

$$v_{N\,o'r}(a) = \varphi_1(v_{chek}(a),\ \psi_N);$$

$$\sigma_N(a) = \varphi_2(v_{chek}(a), \psi_N). (5)$$

The speed of free movement with index N is determined as follows:

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$$v_{N\,o'r}(a)= v_{N\,o'r}(a)+\xi_N-\sigma_N\,(a),\ (6$$

ξ_NWhere, is the parametric coordinate of the vehicle

In modeling, the normal distribution of the velocity of free motion is used. At the same time, the possibility of applying other distribution laws is not excluded.

Taking into account the average length of the route bus, the safety distance along the velocity vector is approximated based on the indicators proposed by V.V. Silyanov.

$$D(v_N)=2.2v_N+7.\ (7)$$

μ_4The transition criterion is more complex and is expressed as follows:

$$\mu_4^{\infty}\ (\propto_N=2)\ \&\ (\propto_{N-1}\neq 3)\ \&\ (\propto_{N+1}\neq 3)\ \&\ (Q=1)\ \&\ \left(v_{N\,quv.o't}>v_{N-1}+\Omega(v_{quv.o't},v_{N-1}\right)\ \&\ \left(\left(\left(\propto_{N+1}^{W}\neq 3\right)\ \&\right.$$

. (8)

Let us reveal the meaning of expression (3.7). The second and third terms of the conjunctive formula express the limitation on overtaking if the vehicle in front or behind has begun to overtake in accordance with the requirements of the Traffic Rules. Equality Q=1 reflects the possibility of overtaking at a given point of the modeled section of the road network, i.e., $Q= Q\,(a)$.

In the model, the variation in the speed of an overtaking vehicle is expressed linearly at a constant speed of overtaking:

$$v_{N\,quv.o't}=v_{N\,vt}k,(9)$$

$k\geq 1$Here, v is the overtaking speed.

$\Omega(v_{quv.o't},v_{N-1})$ the expression shows the magnitude of the increase in the speed of the overtaking car compared to the speed of the overtaking vehicle. The safe interval in the traffic flow moving in the opposite direction required during the overtaking process is determined by the overtaking criterion.

Total overtaking time:

$$T_{quv.o't}=\frac{a_{N-1}-a_N}{v_{N\,quv.o't}-v_{N-1}}+T_{qayt}.(10)$$

T_{qayt}Here, the time it takes for an overtaking vehicle to return to its lane.

Overtaking endpoint coordinate

$$P_N=a_N+v_{N\,quv.o't}T_{quv.o't}.\ (11)$$

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Coordinate of the oncoming or overtaking vehicle at the moment of completing the overtaking:

$G_N^W = H - a_N^W - v_N^W T_{quv.o't}$;

$G_{N+1}^W = H - a_{N+1}^W - v_{N+1}^W T_{quv.o't}$, (12)

Here, H is the length of the modeled section.

Checking the safety of overtaking or the possibility of its execution is performed according to the following criteria:

$B_{xavf} = G_i^W - F_N; i = N,$ N+1 , (13)

$B_{xavf} B_{xavf} \geq 0 B_{xavf} B_{xavf} = 28$ mThe value serves as a criterion for determining a safe overtaking. Overtaking is possible only if there is. The greater the value of , the safer the overtaking will be. The conducted experimental studies established that the criterion required for performing a safe overtaking on the surveyed section is moderate.

B_{xavf}By conducting experimental studies at various values of the criterion determining safe overtaking, it is possible to evaluate the level of traffic safety assurance under given traffic flow parameters.

In the simulated system, without dwelling on the sufficiently generalized open algorithm of aggregates, it is necessary to determine the list of aggregate placement systems that represent the most optimal, complete, and convenient interdependencies between them in the model.

The algorithm for the speed model of public passenger transport moving as part of the traffic flow is presented in Figure 2. Since public transport moves together with the flow, all factors of the flow influence its speed. Therefore, determining the characteristics of traffic flows is of great importance in modeling the speed of public passenger transport.

Modeling of the traffic flow in which the route bus is moving was carried out on a 10 km long street-road network with two traffic lanes with limited speed and unlimited overtaking.

In the simulated section, a speed limit of 90 km/h for passenger cars and 80 km/h for trucks was selected as the initial data. Subsequent experiments were conducted at 80 and 60 km/h, 70 and 50 km/h, 50 and 40 km/h, and 30 km/h for the total flow, respectively. It is assumed that the traffic intensity varies from 500 to 1100 hp with a discrete speed of 200 hp. The composition of the transport flow was 80% passenger cars, 12% trucks, and 8% buses (85-8-7, 82-10-8, 88-7-5 in subsequent experiments, respectively).

As a result of computer experiments, the following statistical indicators are determined:

is the instantaneous and standard velocity of the traffic flow at the exit;

-instantaneous and standard communication speed of public transport;

is the total number of overtakes;

- number of hazardous (emergency) overtakes (B_hazard ≥ 28 m).

Various restrictions on the distribution of free speed (local speed restrictions and speed restrictions under the influence of slow-moving vehicles moving in a traffic flow) were determined

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