Enhancement of fuel consumption regulation for city buses in the Russian Federation

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Abstract. The stages of the development of fuel consumption regulation for vehicles in the USSR and in the Russian Federation are shown, and the main concepts of the research into fuel consumption regulation for buses are described. The paper considers mathematical models to predict fuel consumption for vehicles with regard to high-speed movement modes, and determines fuel consumption for city buses.

1. Introduction
Consumption rates of fuel and lubricant materials are used to plan their consumption and assess the effectiveness of the use of road transport vehicles. The consumption rate of fuels and lubricants for road transport vehicles means a normalized value of their consumption for operating vehicle of a specific model, brand or modification. It is used to calculate a normalized fuel consumption rate at the place of consumption, to maintain statistical and operational reporting, to determine the traffic handling cost and other types of transportation, to plan the needs of enterprises in petroleum, to calculate taxation of enterprises, to implement savings and energy saving of consumed petroleum, etc. [1,2].

The development of state regulation in the field of consumption of liquid fuels for vehicles can be divided into two stages conventionally implemented in the USSR from 1960 to 1991 and in the Russian Federation from 1991 up to the present.

The first stage begins with qualitative changes in fuel consumption regulation that occurred after implementation of the Decree of the Bureau of the Central Committee of the CPSU for the RSFSR, Council of Ministers of the RSFSR of 14.06.1958 No. 637 On Measures to Improve the Performance of Freight Road Transport. Since July 01, 1960, Uniform liquid fuel consumption rates for motor vehicles were put into effect, which approved by the USSR Council of Ministers Decree No. 252 of 05.03.1960 On Liquid Fuel Consumption Rates for Vehicles.

In contrast to previously existing standards, the new standards took into account not only the mileage of vehicles, but also the transportation performed per mileage, as well as the distance of cargo transportation. In addition, these standards are widely differentiated by road and climatic conditions. For buses, the rate was set with allowance for only the total mileage:

\[ Q_n = 0.01 \cdot (H_s \cdot S) \cdot (1 \pm 0.01 \cdot D) \]

where \( Q_n \) is the required amount of fuel, l; \( H_s \) is the norm per 100 km of the bus run, l/100 km; \( S \) is total mileage, km; \( D \) is correction coefficient, %.
Factors that increase fuel consumption of buses: operation in winter; operation on mountainous roads; operation with frequent stops; vehicles after major repair and new vehicles; operation in difficult road conditions; learner-driving.

Factors that reduce the fuel consumption rate: operation on non-urban roads with improved surface.

Heads of motor transport enterprises were given the right to establish route norms for liquid fuel consumption for vehicles operating on the same routes, provided that all the routes are complied with uniform norms for liquid fuel consumption.

The subsequent dramatic development of the country’s road transport industry due to a number of Resolutions of the Central Committee of the CPSU, USSR Council of Ministers on improving the efficiency of production and operation of trucks led to introduction of Linear Consumption Rates of Liquid Fuel for Road Transport on January 1, 1976, and approved by the Resolution of the RSFSR Gosplan of October 29, 1975 No. 206 On temporary Linear Rates of Liquid Fuel Consumption for Road Transport.

However, despite the positive reform of the entire road transport industry, intensification vehicle production and new norms for fuel consumption of buses have undergone only minor changes [2]:

- new models, brands and modifications of buses were added with appropriate fuel consumption rates;
- additional increasing coefficients were introduced for work on roads with a complicated layout.

After the issue of the Order of the Minavtotrans of the RSFSR of 03.09.1982 No. 91 On Strengthening the Economy Mode of Automobile Fuel and Tires, new linear consumption rates of automobile gasoline, diesel fuel and liquefied gas for road transport were introduced, which were approved by the USSR State Plan Resolution No. 171 On Approval of Linear Fuel Consumption Norms for Road Transport.

New rates of fuel consumption of buses that replaced the previous ones have undergone the following changes:

- norms for consumption of liquefied gas per 100 km of run were introduced for buses equipped with gas engines;
- linear consumption rates for gasoline and diesel fuel per 100 km of run were reduced for some bus models;
- new models, brands and modifications of buses were added with appropriate fuel consumption rates.

At the end of the first stage of legislation development in the field of fuel consumption regulation, since 01.07.1989, in accordance with the order of the USSR State Planning Committee of January 6, 1989 No. KM-2/4-9, the previously existing standards were replaced with new linear norms for fuel consumption approved by the Letter of the Ministry of Autotrans of the RSFSR of 28.03.1989 No. BE-14/385 On Approval and Introduction of Linear Fuel Consumption Rates for Road Transport.

New rates of fuel consumption of buses have undergone the following changes:

- consumption norms for compressed natural gas per 100 km of run were introduced for buses and for operation in gas-diesel mode;
- linear consumption rates of motor gasoline, diesel fuel and liquefied gas per 100 km of run were reduced for some models of buses;
- brands and modifications of buses were added with appropriate fuel consumption rates;
- norms of gasoline for gas vehicles were determined;
- new increasing coefficients were introduced: for vehicles in cities with over 1 million people; with a centralized single movement of vehicles under own power.

In addition, since 01.01.1992, the State Standard of the USSR has introduced two regulatory documents:

1. GOST 20306-90 Road Transport. Fuel Efficiency. Test Methods. According to this document, the average speed $V_{av}$, km/h, and average fuel consumption $Q_s$, l/100 km are determined according to the results of road tests in conditions corresponding to the movement on the highway in NAMI’s Testing Centre when specified requirements are met.
This norm defines the following indicators and characteristics of fuel efficiency: check fuel consumption, fuel consumption in the main cycle on the road, fuel consumption in the urban cycle on the road, fuel consumption in the urban cycle on the stand, fuel characteristics of steady motion, and fuel-speed characteristics on the main hilly road.

2. GOST 22576-90 Road Transport. Speed Characteristics. Test Methods. According to this document, the speed is \( v_{\text{max}} \), km/h, and the time \( t \), s, of vehicle movement on roads that comply with the specified requirements are calculated by the established expressions.

This standard defines the following indicators and properties of the vehicle speed characteristics: maximum speed, acceleration time on a given path, travel time to a given speed, acceleration-overrun speed, gear acceleration for maximum speed.

The analysis of the first stage shows that, in addition to a qualitative change in rationing of fuel consumption in 1960 (transportation performed, differentiation relative to road and climatic conditions, etc.), the procedure for tests of the speed characteristics and fuel efficiency of vehicles, later used by NIIAT to develop the Methodology for Determination of Basic Fuel Consumption Standards for Road Transport no other qualitative changes occurred by the early 1990s: some norms and adjusting factors decreased, the vehicle model range with approved norms increased, adjusting factors and types of fuel were added.

The second stage in the development of legislation in the field of fuel consumption regulation begins with the introduction of Rates of Consumption of Fuels and Lubricants for Road Transport RZ112199-0295-93 approved by the Department of Road Transport of the Ministry of Transport of the Russian Federation on 26.08.1993, and the issue of the Instructive Letters of the Ministry of Transport of the Russian Federation of February 13, 1995, No. LS-1/52 On Introducing Clarity into Consumption Rates of Fuels and Lubricants for Road Transport.

According to new norms for road transport, the following types of consumption norms were applied: linear norms regulating fuel consumption for a moving car, fuel consumption rates for work of special equipment installed in vehicles, and specific fuel consumption rates per unit of transportation performed.

Compared with the previous norms, the changes are as follows:

- differentiation of norms by types of vehicles (cars, buses, onboard trucks, tractors, dump trucks, vans) due to an increased number of models for which the norms are regulated, and for some models, the norms for vehicle configurations with different engines are provided;

- fuel consumption rates for buses take into account the operation of heaters in the compartment:

\[
Q_h = 0.01 \cdot (H_s \cdot S) \cdot (1 \pm 0.01 \cdot D) + H_{\text{heater}} \cdot T
\]

(2)

where \( H_{\text{heater}} \) is the fuel consumption rate for heater operation, l/h; \( T \) is car operation time with the heater turned on, h.

Later, on November 23, 1994, the Department of Automotive Transport of the Ministry of Transport of the Russian Federation approved the Guidelines for Energy Saving in Road Transport R 3112199-0337-95. According to this document, measures were developed to ensure economy and rational use of fuel and lubricants, rational use of vehicles, and recommendations to employees engaged in transportation. In particular, the service of operation of regional transport company (RTC) and vehicles was recommended:

- to regulate speed with regard to the most economical operation mode and to develop special technological maps of rational bus management on each route (for intercity bus traffic);
- to take into account the condition and profile of roads, their technical condition, condition of access roads, traffic intensity, the presence of traffic lights and level crossings, etc., in routing;
- to ensure that each car complies with simultaneous recording of the indications of speedometers and residual fuel in tanks;
- to determine the technical condition of the vehicle, to check routes, operation conditions on this route, etc., it was recommended to perform selective tests to check fuel consumption of RTC vehicles.

In addition, according to the list of the main R&D projects on energy conservation, NIIAT, and NAMI and MADI are assigned to develop, refine and supplement linear fuel consumption rates for road vehicles, and developing methods and software for calculating fuel consumption operating standards for...
ATS. As a result, on September 24, 1996, NIIAT developed and the Ministry of Transport of the Russian Federation approved without restriction on the period of validity the Method of Determining Basic Fuel Consumption Norms for Road Transport R 03112134-0367-97 pursuant to the Law of the Russian Federation On Energy Saving No. 28-FZ of 03.04.1996 and Decree of the Government of the Russian Federation On Urgent Measures for Energy Saving No. 1087 of 02.11.1995.

The basic norms of fuel consumption take into account:

- vehicle design parameters;
- standard typed routes:
  1. Route in medium-hilly terrain (with a slope of up to 4%), the route length is 14.6 km, and speed limits are set depending on the type of the vehicle (long-distance and tourist buses, as well as suburban and local traffic at speeds of 60 and 80 km/h; city bus speeds of 40 and 60 km/h).
  2. The city route, the route length is 3.9 km, and the route consists of 7 sections of different length and speed limits (from 20 to 80 km/h).
  3. The city bus route, the route length is 2.2 km, and the route consists of 6 sections of different length and speed limits (from 30 to 50 km/h).

In addition, weight coefficients of operation costs were introduced for cars and buses.

However, the rated fuel consumption for a particular vehicle is calculated by the known formulas (The Order of Fuel Consumption Ration for Road Transport and P3112199-0295-93) considering the basic rate and correction factors.

According to the plan for consumption rates, since 01.01.1997, new Fuel Consumption and Lubricant Consumption Standards for Road Transport P 3112194-0366-97 approved by the Ministry of Transport of the Russian Federation on April 29, 1997, are replaced the existing ones to provide the following changes in fuel consumption regulation for buses:

- linear consumption rates of motor gasoline, diesel fuel, liquefied gas, compressed natural gas per 100 km of run for some models of buses were reduced;
- models, brands and modifications of vehicles were added with appropriate fuel consumption rates;
- the wording and meanings of some of the existing adjusting factors were changed and new adjusting factors were introduced: increasing factor, when fuel consumption rates for operation in cities were divided into groups depending on the population of cities (up to 0.5 mln, from 0.5 to 2.5 mln and more than 2.5 mln people; the length of the suburban area of cities was established: for cities with more than 2.5 mln people, it is up to 50 km from the city border, for cities with population from 0.5 to 2.4 mln people, it attains up to 15 km, and for cities with less than 0.5 mln people, it is up to 5 km;
  - for new models and modifications of vehicles with basic fuel consumption rates unapproved by the Department of Automobile Transport of the Ministry of Transport of the Russian Federation, temporary norms should be established in accordance with the requirements of the “Method for Determining Basic Fuel Consumption Norms for Road Transport approved by the Federal Road and Road Service on October 14, 1996.

The following Fuel and Lubricant Consumption Rates for Road Transport P 3112194-0366-03 were approved by the Ministry of Transport of the Russian Federation on April 29, 2003 and introduced since January 1, 2003. According to this document, the following changes and additions were made:

- new models, brands and modifications of buses were added with appropriate fuel consumption rates, including those for vehicle configurations with different engines and gearboxes;
- the wording and meanings of some of the existing adjusting factors were changed and new adjusting factors were introduced: increasing factor, when fuel consumption rates for operation in cities were divided into groups depending on the population of cities (up to 100 th, from 100 to 250 th, from 250 th to 1 mln, from 1 mln to 3 mln and over 3 mln people); the reduction factor is removed for rented and corporate buses that do not operate on regular routes.

In the future, in order to implement the Order of the Ministry of Transport of 24.06.2003 No. 153 On Approval of the Instruction on Accounting for Income and Expenses for Conventional Activities in Road Transport (registered by the Ministry of Justice of Russia on July 24, 2003, registration number 4916), according to the Order of the Ministry of Transport of the Russian Federation of March 14, 2008 No.
AM-23-p, new Fuel and Lubricant Consumption Rates for Road Transport were introduced (hereinafter referred to as Norms).

In accordance with the new norms for general-purpose vehicles, the following types of standards are established:
- basic rate, l/100 km run of the bus in the equipped state;
- transport norm, l/100 km run of the bus during transportation, which takes into account the curb weight and the rated load of passengers normalized depending on the purpose.

The operational rate is set at the place of vehicle operation with regard to the basic or transport norm using adjusting factors (allowances) that take into account local operating conditions.

Compared with the previously existing one, and according to the new Norms in fuel consumption rationing, only minor changes were made:
- new models, brands and modifications of buses were added with appropriate fuel consumption rates;
- the wording and meanings of some effective adjusting factors were changed.

In April 2012, in accordance with the Decree of the Government of the Russian Federation of July 29, 2011 No. 633 On the Expert Evaluation of the Regulatory Legal Acts of the Federal Executive Bodies in Order to Identify Provisions that Unreasonably Hinder Entrepreneurial and Investment Activities, and Amendments to Some Acts of the Government of the Russian Federation, Order No. 634 of the Ministry of Economic Development of Russia of November 9, 2011 On Approval of the Procedure for Conducting Expertise of Regulatory Legal Acts of Federal Executive Bodies to Identify Provisions that Unreasonably Hinder Business and Investment Activities, and the Plan for expertise of regulatory legal acts of federal executive bodies of the Ministry of Economic Development of the Russian Federation performed expertise of the order of the Russian Ministry of Transport dated March 14, 2008 AM-23-r On Methodical Recommendations Norms of Fuel Consumption and Lubricants for Road Transport.

According to the results of the expertise of the order in accordance with Paragraph 3 of Resolution No. 633, the Ministry of Economic Development of the Russian Federation considers it necessary:
- to exclude from Clause 3 the reference that the norms for consumption of fuel and lubricants in road transport are intended for calculation of taxation and for maintaining statistical reports;
- to determine an unambiguous procedure for approval and change of correction factors to fuel consumption rates;
- to indicate the advisory nature of the order;
- to approve the procedure for periodic updating of the provisions of the order in relation to the used fleet of vehicles, including updating the provisions of the order with regard to proposals of business entities;

The order No. NA-50-r of the Ministry of Transport of the Russian Federation On Amendments to the Methodical Recommendations Consumption Standards of Fuels and Lubricants for Road Transport of May 14, 2014 enacted by the order of the Ministry of Transport of the Russian Federation of March 14, 2008 No. AM-23-r, and later the order of the Ministry of Transport of the Russian Federation of July 14, 2015 N ON-80-r were issued. According to these documents, the list of vehicles is supplemented by new models with the appropriate basic norms. The latest revision of fuel consumption norms for 2008 was implemented on September 20, 2018. No other changes have been made.

Simultaneously with the development of legislation in the field of fuel consumption rationing, scientific theories were developed in the field of fuel efficiency, planning and regulation of fuel consumption for vehicles:
- methods of route regulation (forecasting) of fuel consumption were developed or improved taking into account various parameters (speed, condition of the road surface, degree of vehicle loading, design parameters of vehicles, etc.) for certain categories of vehicles (cars, buses, trucks, saddle and trailer trucks, dump trucks);
- the dependences of the impact of various operating conditions (urban, winter) on fuel consumption of any categories of vehicles are investigated.
In dissertation research, S.N. Abramova (NIAT, 1983); V.I. Dzhadzhianidze (MADI, 1991); A.A. Koryakina (MADI, 2000); Ispolatova B.Yu. (MSIU, 2005) improved methods for developing fuel consumption norms for buses based on:

- accounting of traffic on urban and suburban bus routes using established quantitative relationships between the parameters of routing of urban and suburban buses and fuel consumption, the developed method of adjusting fuel consumption norms when changing technology of route buses and method used to calculate route norms of fuel consumption for urban and suburban buses;
- methods of route rationing of fuel consumption for vehicles that takes into account the specificity of the formation of fuel consumption of buses and allows differentiation of fuel consumption rates on each route using a theoretical model of the formation of linear fuel consumption of buses relative to the operation mode on the route;
- methods for developing route norms for fuel consumption of buses on urban routes formed with respect to indicators of operating conditions that have the greatest impact on fuel consumption;
- reasonable choice of the main factors that affect the route fuel consumption of city buses, a multi-factor mathematical model of the route fuel consumption of bus in operation mode using the example of LiAZ-6212.

With regard to the definition of fuel consumption of buses, the general formula of a regressive model of operating fuel consumption is recommended (the symbols in the following expressions are edited by the authors):

\[
Q = b_0 + b_1 P + b_2 V_c + b_3 l + b_4 i + b_5 P^2 + b_6 V_c^2 + b_7 l^2 + b_8 i^2 + b_9 P V_c + b_{10} P l + b_{11} P i + b_{12} V_c l + b_{13} V_c^2 i + b_{14} l l
\]  

(3)

where \(b_0 + b_{14}\) are regression coefficients; \(P\), person is passenger traffic per turnover; \(l\), km is the length of the movement cycle; \(i\), % is the slope of the road; \(V_c\), km/h is the speed of movement.

Based on the analysis of the main factors affecting fuel consumption of city buses, their route norms can be calculated according to the following mathematical model:

\[
Q = 76.55 - 0.42 V_{av} - 13.43 l_t + 7.22 n_{turn} - 0.33 G_c - 0.017 l_{av.d} - 0.074 t
\]  

(4)

where \(V_{av}\), km/h is the average speed on the route; \(l_t\), km is the average trip length (average distance between stops); \(n_{turn}\), turns/km is specific number of turns (obstacles) on the route; \(G_c\), ind/m², is the actual number of passengers in the bus (passengers capacity); \(l_{av.d}\), km is the average daily bus mileage; \(t\), °C is ambient temperature.

At the same time, the author of the paper reports the prevailing effect of the average speed (about 35%) on fuel consumption compared to other factors, the speed values for this study are based on statistical data.

The conducted research enabled development and introduction of norms of fuel consumption in several cities for a large number of urban and suburban bus routes. At the same time, the proposed regression mathematical models of fuel consumption are complicated for use due to the obvious ambiguity of the physical and mathematical meaning of the approximating coefficients and their values. According to the previously conducted studies, the calculation of fuel consumption cannot and should not be easy due to the effect of numerous random factors on vehicle fuel consumption.

The advantages of the existing regulation system of vehicle fuel consumption is its obvious simplicity, and the values of the basic norms of fuel consumption obtained by the NIAT method and provided in the annexes to Norms differ slightly from the calculated and actual values. The studies carried out at the Department of Automobile Transport, NSTU named after R.E. Alekseev [1,2], show that the deviations of the basic norms and calculated values of fuel consumption do not exceed 7% (up to 1.8 l/100 km) for trucks. At the same time, the existing procedure for correcting the transport norm on operating conditions was proved to be ineffective. In similar conditions, the obtained fuel consumption rates exceed the estimated costs by up to 26% (for trucks).

To eliminate these shortcomings, we developed a probabilistic-analytical method for predicting fuel consumption with regard to the speed of movement with mathematical models (5,10) of the most probable average speed of movement and fuel consumption under given operating conditions [2]:
1. The most probable value of the average vehicle speed $V_{av}$ on the route section $j$ (urban, suburban and out-of-town) with regard to the engine operating mode $s'$:

$$V_{cj}^s = \frac{3.6 \cdot P_e^s \cdot r_d}{T_f^s \cdot i_0} \sum_{i=1}^{n} \frac{k_i}{\sum_{i=1}^{n} \delta_i}$$

(5)

where $P_e^s$ is the effective engine power in the selected operating mode, W; $r_d$ is the dynamic radius of the drive wheel, m; $T_f$ is torque, N·m, with a corresponding value of effective power $P_e$; $i_0$ is final drive gear ratio; $n$ is the number of gears; $i_g$ is gear ratio; $k_i$ is road conditions factor; $\delta_i$ is transportation conditions factor.

The road conditions factor $k_i$ characterizes the vehicle movement in each gear of the gear box and is numerically equal to the probability of the vehicle movement in one gear or another under given road conditions.

The transport conditions factor $\delta_i$ characterizes the position of the mathematical expectation of the speed in the gear in the interval of speeds available for this gear and is calculated with regard to distribution of the actual speeds in the gear as a random variable.

The first factor of expression (5) is the vehicle operation speed in direct drive ($i_{gb} = 1$), which is assumed to be conditionally constant for a particular car model, characterizes the performance of the vehicle and is subject to adjustment with regard to the maximum allowable speed values.

The second factor under the sum sign is a complex operating conditions factor, which is an unconditional variable in various operating conditions and is not strictly varying in the range from 0 to 1 (0 is unacceptable conditions for movement; 1 is no effect of operating conditions on movement). The factor characterizes the change in traction capacity of the vehicle in certain operating conditions.

This model shows high convergence of the results with actual average speeds (for trucks deviations of not more than 1.7% (not more than 2 km/h)) in case of technically competent driving. But it should be noted that the model involves uniform movement of the vehicle at a constant average speed as prevailing in intercity and international cargo transportation. Therefore, the model can be used for buses, but it requires clarification with regard to the specifics of urban traffic.

For these purposes, the following studies are underway at the Department of Automobile Transport, NSTU:

a) Distribution of road resistances as a random variable in movement on paved roads through an example of the city of Nizhny Novgorod.

To solve this problem, 3 laws of distribution of a random variable $\Psi$ were proposed as a hypothesis: uniform law; exponential law; gamma distribution.

The condition for constructing a graphical dependence of the probability of distribution of a random variable is written as:

$$f(\psi) = \begin{cases} f(x), & \text{at } \psi_{min} < \psi \leq \psi_{max} \\ 0, & \text{at } \psi > \psi_{max} \text{ or } \psi < \psi_{min} \end{cases}$$

(6)

The uniform law of distribution of road resistance can be used when any value in the range of $\psi$ variation is equally probable, which is possible in the period of instability of climatic conditions or the state of the road surface.

The exponential law of distribution of road resistance can be used when the most probable $\psi$ value is close to the range limits (close to $\psi_{min} - \psi_{max}$ in case of prevailing high quality of the road surface, for example, after the road overhaul (negative exponent); close to $\psi_{max} - \psi_{min}$ in the movement on the road with the same coating, but of unsatisfactory quality (positive exponent).

The gamma distribution of road resistance can be used when the most probable $\psi$ value refers to a specific value in the given interval $\psi_{min} < \psi < \psi_{max}$. This is the most common case of $\psi$ real distribution as a random variable, which in a particular case reduces to a normal one if the most probable value tends to the weighted-mean value $m(\psi)$.

The studies carried out at the Department of Automobile Transport, NSTU, which involved senior students of the department, confirmed normal distribution of road resistance in Nizhny Novgorod. The
The mathematical expectation of road resistance was \( m(\psi) = 0.0129 \) for wet asphalt surface. Changes in road resistance for other states of surface are underway.

The form of \( \psi \) distribution law determines the mathematical form of the expression for calculation of the road conditions factor \( k_i \). For normal distribution, it takes the form:

\[
k_i = \int_{D_i}^{D_{i+1}} f(\psi) d\psi = \Phi \left( \frac{D_i - m(\psi)}{\sigma(\psi)} \right) - \Phi \left( \frac{D_{i+1} - m(\psi)}{\sigma(\psi)} \right),
\]

where: \( D_i - m(\psi) = z \) is the argument of the normalized function; \( \Phi(z) \) is the value of the normalized function; \( D_i \) and \( D_{i+1} \) is the dynamic factor for the current and next gear; \( \sigma(\psi) \) is a standard deviation of the random variable \( \psi \).

b) The distribution of speeds of buses of classes \( M_1, M_2, M_3 \) on the routes in Nizhny Novgorod and in gears to identify their change patterns and to adjust the mathematical type of factor \( \delta_i \).

To solve this problem, the studies which involved senior students were carried out to investigate the speeds of buses LiAZ-5256 with hydromechanical actuator and PAZ-3204 on the routes in Nizhny Novgorod. The laws of speed distribution for various gears (from the exponential for low gears to the normal and derived three-parameter law for medium and high gears) were defined.

The form of the \( V_i \) distribution law determines the mathematical form of the expression for calculation of the transport conditions factor \( \delta_i \). Due to a small range of speed changes in urban conditions (from \( V_{min} \) to \( V_{max} = 60 \text{ km/h} \)) and the speed range for each gear, this factor can be defined with a relatively small error (up to 20%) as for the middle position of the interval for each gear:

\[
\delta_i = \frac{1}{2} \left( 1 + \frac{V_{i,min}}{V_{i,max}} \right)
\]

where: \( V_{i,min} \) and \( V_{i,max} \) are the minimum stable and maximum speed of the bus in gear, respectively.

Expressions for calculation of the factor \( \delta_i \) for buses with HMT are derived.

c) Determination of the mathematical form of the additional factor to expression (5), which characterizes irregular movement of the bus on straight sections of urban routes and turns, taking into account safety of movement (no sideslip and skid).

From the critical speed expression according to the sideslip and skid conditions [3], the mathematical form of the urban operating conditions is as follows:

\[
k_i = \sqrt{(\varphi_x^2 - \chi^2)}
\]

where: \( \varphi_x \) is the factor of transverse adhesion of tires with the road; \( \chi \) is the brake (or traction) force factor (ratio of force to weight per wheel).

Multiplying the numerical value of the given coefficient by the average speed of the bus in case of irregular movement gives the numerical value of the average speed of the bus in urban conditions in the range of [20; 35] km/h, which is in good agreement with the experimental average speeds of buses in the city of Nizhny Novgorod (\( V_{av} = [22; 28] \text{ km/h} \)).

2. The most probable value of fuel consumption of the vehicle \( Q_s \) on the section of the route \( j \) (urban and suburban) with regard to the mode of operation of the engine \( s \):

\[
Q_{s,j} = \frac{g_{ep} \cdot k_{E}^{s} \cdot k_{Lij}^{s}}{10000 \cdot \rho_f \cdot \eta_{tr}} \left( 0.278 \cdot m_{\psi} \cdot G_v + 0.02143 \cdot W \cdot \varphi_x^2 \right)
\]

where \( g_{ep} \) is specific fuel consumption of the engine at maximum power; \( k_{E}^{s} \) and \( k_{Lij}^{s} \) are the factors of speed (E) and load (L) modes of the engine; \( \rho_f \) is density of fuel, kg/l; \( \eta_{tr} \) is transmission efficiency; \( m_{\psi} \) is mathematical expectation of road resistance; \( G_v \) is the total weight of the vehicle, H; \( W \) is wind shape factor.

Based on the study [4] carried out at the Department of Cars and Tractors, NSTU, \( k_{E}^{s} \) and \( k_{Lij}^{s} \) factors were determined for the values of angular speeds of the drive shaft and operation modes of the engine,
corresponding to the average speed \( V_{c,ij} \), km/h on different sections of the route (\( i \) and \( j \) are the gear number and the route section, respectively).

This model showed high convergence of results with actual fuel consumption (for trucks deviations of not more than 4.85% (not more than 2 l per 100 km)) in case of satisfactory technical condition of the vehicle and fuel equipment settings. But it should be noted that the model is based on the equation of fuel consumption of steady-state movement as prevailing in interurban and international transportation. Therefore, the model can be used for buses, but it requires clarification with regard to the specifics of irregular movement.

For these purposes, the studies on partial speed and load characteristics of the engines and the most likely modes of engine operation of buses are underway at the Department of Automobile Transport, NSTU.

The calculation of fuel consumption in urban conditions is divided into two parts for the purposes of this study: a) when the bus is moving with a calculated average speed according to the dependencies described above – the equation of fuel consumption for unsteady motion; b) idle time of the bus at stopping points (SP), at regulated intersections, etc. – as hourly consumption of the engine.

The senior students of the Department of Automobile Transport, NSTU, [5] and the Department of Transport and Communications of the city of Nizhny Novgorod were involved in the studies to establish the laws of distribution of the total idle time of the bus at SP for the city of Nizhny Novgorod.

The total time\( t_z \) of delay (idle) of the bus at SP is described by the equation:

\[
\sum t_z = t_{add} + t_{do} + t_{service} + t_{idle} + t_{dc} + t_{dep}
\]  

where: \( t_{add} \) is additional time required for bus arrival (change) at the bus station; \( t_{do} \) is the door opening time; \( t_{service} \) is service time (boarding-debussing) of passengers; \( t_{idle} \) is idle waiting time for passengers; \( t_{dc} \) is the time of closing doors; \( t_{dep} \) is the time of the bus departure from SP in case of the traffic lay-by.

For the study, part of fuel consumption calculated as hourly consumption of the engine is due to the components of the total idle time at SP: \( t_{do} = t_{dc} = 1–2 \) s; \( t_{service} \) and \( t_{idle} \), for which distribution histograms were obtained [5].

The distribution of passenger service time with high convergence is described by two distribution laws: gamma distribution or log-normal distribution (Figure 1) with the numerical value of mathematical expectation of 12–15 s for the city of Nizhny Novgorod.

![Figure 1. Passenger service time – log-normal distribution.](image1)

![Figure 2. Passenger waiting time – exponential distribution.](image2)

The distribution of passenger waiting time is described by the exponential distribution (Fig. 2) with a numerical value of the expectation of 20–40 s for the city of Nizhny Novgorod. This idle time was recorded only for SP with the highest passenger turnover on the bus route (not more than 2–3 SP for the entire route).
The total fuel consumption of the bus on the route is calculated in the range from the average bus occupancy (based on experimental data) and the maximum bus capacity. This enabled calculation of the most likely value of fuel consumption for the given route.

This study results in an improved probabilistic-analytical method for predicting fuel consumption with regard to the speed rate. This method will be the basis for development of recommendations for regulation of fuel consumption of city buses.

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