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Bus Passenger Transportation Quality Indicators: Organization of Instrumental Research of Additional Environmental and Sanitary Factors

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ABSTRACT

The increase in vehicle-to-population ratio, in the number of personal cars and of individual travels defines extra requirements to the public transport service quality and safety within the public municipal passenger transport system.

However, while specifying such requirements, the relevant regulations do not always consider the factors important for passenger service quality and driver work such as comfort and more general health and environmental standards.

The purpose of the research is to identify additional factors that affect the city bus passenger service quality, to develop experimental test procedure and to conduct instrumental analysis of the transport service quality in accordance with the social standard as well as of additional parameters that influence it.

The article presents the results of the following parameter measurements and sampling taken in the Moscow city buses: pollutants (hydrocarbons, formaldehyde, carbon (II) oxide and nitrogen dioxide) and artificial lighting (total illumination, lux, percent flicker, %), noise level, vibration, micro-climate.

Based on measurements of harmful substances in the air of the bus passenger compartment, parameters of the micro-climate, artificial lighting, acoustic noise levels and general vibration, it was stated that they are within the limits of the permissible norms including those set by the European Union and WHO. Hence, the public transport service quality with reference to the proposed group of additional factors complies with standard requirements. It is proposed to extend the researches to other seasons as well as to other types of vehicles.

Keywords: *transport, urban public transport, transport service quality, new management model for land municipal passenger transport (NMM for LMPT), noise, vibration, micro-climate, pollutants, artificial lighting, Moscow.*

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Introduction

Following the growth of the vehicle-to-population ratio, the number of private cars and individual trips in Moscow, extra requirements are applied to the public transport service quality and safety in the public municipal passenger transport system [1].

Based on an analysis of the current state of the municipal passenger transport system [2], previous scientific researches [3–5] and assessment of the best foreign experience [6], Moscow City Department of transport and road infrastructure development has been implementing a number of projects focused on significant improvement of transport service quality and safety. The most important activity for improving the public transport service quality when using the land municipal passenger transport is the transition to a new management model in Moscow (NMM for LMPT). NMM for LMPT provides integration of private motor transport enterprises into the Moscow public transport system with transition to common service standards.

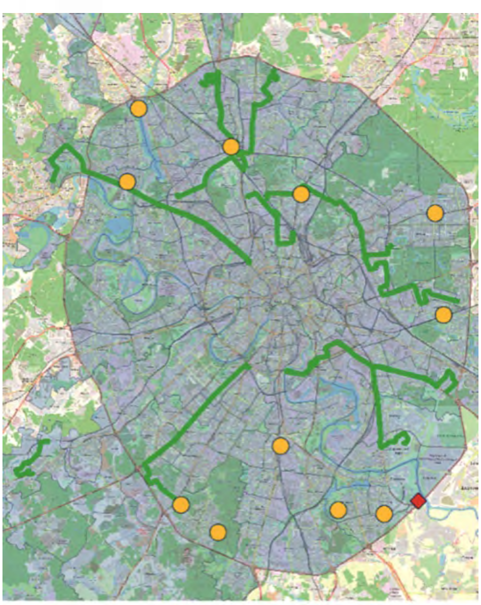
The commercial motor transport enterprises are admitted to the operation of regular city passenger routes based on the public contracts following the results of the open tenders.

With the transition to the NMM for LMPT, a new route network has been developed and implemented considering duplicate route elimination, traffic congestion reduction, traffic interval reductions and subsequent adjustment of the timetable. Optimal class of vehicles has been determined for each route.

Provision is made for the automatic control of transport service quality as well as for field monitoring the rolling stock operation. The set of controlled parameters was determined: compliance with the route, speed mode, respect of timetable, compliance of type of vehicles to the contracted one; cleanliness of the passenger compartment, serviceability of the ramp for people with limited mobility, etc.

However, current regulatory instruments and laws governing quality indicators and their normalized values take no account of the factors, which influence the passenger service quality inside the vehicle [7; 8].

The *objective* of the research is to identify major factors that affect the drivers and passengers inside the vehicle and to perform the relevant *instrumental analyses.*



Pic. 1. Trajectories of the routes to be examined.

Determining conditions of testing

Large, medium and small vehicles serving the chosen regular municipal routes were selected as target objects of research.

Based on the results of the previous hierarchical cluster analysis using Euclidean distances as a distance measure and single-linkage clustering according to the Ward's method, 10 routes have been selected to be assessed [9]. Diagram of the routes to be assessed is shown in Pic. 1.

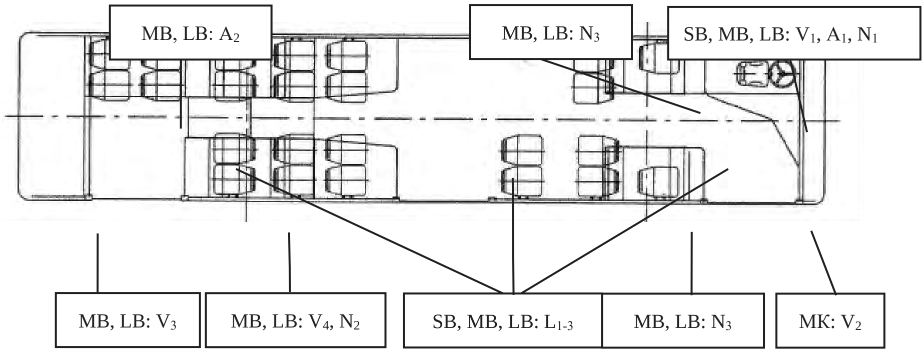
Measurements were performed inside the vehicles served by commercial enterprises within the public contracts for provision of public transport services using motor vehicles on the regular city passenger and luggage routes.

LiAZ-5292.65 was chosen as a large-class vehicle, LiAZ-4292.60 was chosen as a medium-class vehicle and Ford Transit as a small-class vehicle.

The following instrumental analysis and sampling were performed:

1. air sampling for chemical analysis in search for saturated hydrocarbons, formaldehyde, carbon (II) oxide and nitrogen dioxide;

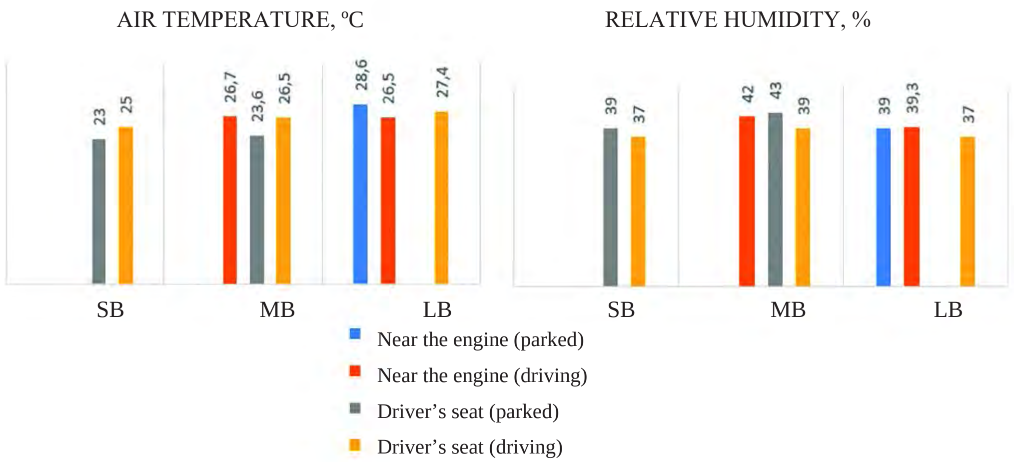
2. micro-climate parameter measuring (air temperature, *C,* relative air humidity*,%,* air velocity, m/s);



Pic. 2. General sampling and measuring diagram.
References for Pic. 2: SB – Small Bus; MB – Medium Bus; LB – Large Bus; N – Noise level measuring point; V – Vibration measuring point; A – Air sampling point and micro-climate parameter measuring point; L – Artificial lighting parameter measuring points.

Pic. 3. Measuring process inside the large vehicle.

Pic. 4. Measuring process inside the small vehicle.



Pic. 5. Sampling Conditions.

3. artificial lighting parameter measuring (total illumination, lux, percent flicker*, %)*;
4. noise-level measuring;
5. vibration measuring.

All used measuring instruments have passed the state metrological calibration test.

The diagram for sampling and measuring in the small, medium and large buses is shown in Pic. 2.

The selected parameters were evaluated in the autumn-winter period.

Measuring process inside the vehicles is presented in Pics. 3, 4.

Measuring process management

General vibration inside the vehicles. Measurements are performed inside the vehicles. The vibration inverter mounting (vpm) disk is fixed at the measuring points B_i (Pic. 2 – vibration measuring points – B_i).

The purpose of this analysis was an instrumental evaluation of the general vibration levels at the driver's and passengers' seats according to [10] and a comparison of the measured values with the maximum permissible levels stated in regulatory documents [10–12].

The running engine and transmission noise acts as a source of general vibration at the driver's seat and inside the passenger compartment. General vibration at B_i is specified by the vibration acceleration component levels within octave interval from 1 Hz to 63 Hz [13, it. 1]. Exceeding any specified parameters is considered as exceeding the maximum acceptable level.

The vibration inverter mounting disk was used as an auxiliary instrument for measuring the vibration level according to [13].

During measuring, the main legal documents used were [10–16].

Prior to measuring, the vpm meter calibration was 10 m/s^2 (peak acceleration value) and after measuring, it was 10 m/s^2.

General vibration level measurements were performed by the procedure stated in [13] and their results were evaluated according to [12]. The three-component vibration inverter mounting platform was fixed on the seat inside the vehicles at the measuring points B_i. At points BT_i the horizontal vibration inverter axis X was directed parallel to the vehicle center line, axis Y was perpendicular to axis X and axis Z was directed vertically (right-handed coordinate system).

These measurements were performed by the procedure stated in [13]:

• in the parking lot, with the bus's closed doors and windows, with power off (background values);

• in the parking lot, with the closed doors and windows of the bus, power on, during operation of the warm engine at idle at 1000 rpm (according to the tachometer);

• when driving through a vehicle-free street (no other vehicles in adjacent lanes), without reflective structures on the roadside, using direct transmission, at 55 km/h.

Measurements were performed at the following points:

• at the driver's seat (B_1);

• at the passenger seat to the right of the driver (B_2);

Table 1

Artificial Lighting Parameters

Measuring Points Small Bus		Average illumination, lux		
		Medium Bus	Large Bus	
C_1	0,0 m	123±15	114±11	153±20
	1,0 m	193±35	150±22	205±28
C_2	0,0 m	119±11	136±20	177±11
	1,0 m	177±35	251±34	270±39
C_3	0,0 m	117±15	109±7	102±2
	1,0 m	180±40	147±21	202±35

- at the passenger seat near the engine (B_3);
- at the passenger seat above the rear axle (B_4).

Standard test uncertainty regarding sound pressure level is +0,7 dB(A), regarding general vibration it is +1,5 dB(A).

Measurements of the vibration acceleration component levels along axes X, Y, Z (dB) were performed in the range of the octave band center frequencies of 2, 4, 8, 16, 31,5 and 63 Hz.

Pollutants quantitative. Chemical air analysis is carried out in accordance with [17–19]. Sampling and measurements were performed by the *procedure* stated in [17]. The searched components are as follows: formaldehyde, hydrocarbon, nitrogen dioxide, carbon (II) oxide.

The samples were taken in the parking lot, at the driver's seat (Pic. 2, point O_1) and inside the vehicle near the engine (Pic. 2, point O_2) while driving and parking.

Sampling and direct measurements were performed in the following order:

1. the bus engine and transmission systems warmed up for 20 minutes;

2. when driving at 40–50 km/h (according to the bus metering devices), when the bus heating/ventilation/air conditioning system was in operation. Air samples were taken within 20 minutes, and direct measuring of concentration of pollutants inside the small vehicle as well as at 2 points inside the medium and large vehicles (at the driver's seat and near the engine in the passenger compartment) was made;

3. the bus was parked so that the exhaust fumes were blown away by the wind towards the opposite of the bus, a control measure of carbon monoxide and hydrocarbon concentrations at the site was carried out;

4. the engine was shut down, there was an intensive airing of the bus compartment;

5. doors and windows were closed, ventilation and air conditioning system was switched on in recycling mode and, under these conditions, the air samples were taken, measurements were performed;

Sampling conditions are shown in Pic. 5.

The sample analysis results have been compared with the values of the maximum permissible concentration, including the values set by the European Union.

Maximum formaldehyde content was 0,013 mg/m^3 when measuring at the driver's seat whilst the small-class vehicle was parked. Hydrocarbon level did not exceed 50 mg/m^3 and nitrogen dioxide level did not exceed 0,042 mg/m^3.

Maximum carbon (II) oxide content was 2,9 at the driver's seat in the small vehicle while driving.

Lighting. Artificial lighting parameters were measured during normal operation of interior lighting with running engine. Provision is made for artificial, top lighting with ceiling fittings. Background natural illumination was no more than 5 %. The measurement plane is horizontal, measuring was carried out at the floor level and 1,0 m from the floor. The operating voltage of mains and installation at the beginning and end of measuring was $U_1 = U_2 = 12$ V.

Normalization of measurements of artificial lighting parameters was performed in accordance with [20–22].

Uncertainty in measures Δ was no more than 1,0 %. Percent flicker was 0 % at all measuring points. The results of measurements of artificial lighting parameters are stated in Table 1.

Micro-climate. Air temperature and relative humidity measurements were performed inside the vehicle to evaluate the micro-climate parameters. The measurements started 20 minutes after the measurement device had been put into working mode. Measuring frequency was equal to three times at each point (Pic. 2, points C_1–C_3) with no less than 5 minutes interval. The results of measurements of micro-climate parameters are stated in Pic. 5. Expanded test uncertainty Up = ±10 %.

When measuring the micro-climate parameters in the small vehicle, the outdoor air temperature was 5,5 C, relative humidity was 72 %, atmospheric pressure was 755 mm Hg.

When measuring the micro-climate parameters in the medium vehicle, the outdoor air temperature was 13,5 C, relative humidity was 69 %, atmospheric pressure was 751 mm Hg.

When measuring the micro-climate parameters in the large vehicle, the outdoor air temperature was 14,7 C, relative humidity was 67 %, atmospheric pressure was 748 mm Hg.

Noise. Acoustic noise levels were measured inside the vehicles' compartments. A microphone stand was mounted at the following measuring points N_i (Pic. 2 – Noise measuring points N_i).

The running engine, transmission, ventilation and air conditioning system noise acts as a noise source at the driver's seat and inside the passenger compartment. Spectrums of noise are broadband and do not contain tonal components. Noise is constant in character. Noise at N_i is specified by energy equivalent sound levels A – LA_{eq}; and octave band sound pressure level. Exceeding any specified parameters is considered as exceeding the maximum acceptable level.

During measuring, the main legal documents used were [11; 16; 20–24]. The instrumental evaluation of the noise levels at the driver's and passengers' seats was made according to [23] followed by comparison of the measured values with the maximum permissible levels stated in the regulatory documents [11; 23].

The measurements were performed:

• in the parking lot, with the closed bus doors and windows, with power off (background values);

• in the parking lot, with the closed doors and windows of the bus, with power on, during operation of the warm engine at idle at 1000 rpm (according to the tachometer);

• when driving through a vehicle-free street (no vehicles in adjacent lanes) without reflective structures on the roadside, on direct transmission at 55 km/h.

• when driving through a vehicle-free street (no vehicles in adjacent lanes) without reflective structures on the roadside, on direct transmission at 50 km/h, with acceleration to the permissible 80 km/h.

When measuring the microphone stand was mounted at N_i. The microphone was pointed forward and fixed at the driver's head height (shifted to the right, 0,2 meters from the driver's head. The microphone was directed forward in the direction of travel). Measurements were performed at the following points:

• at the driver's seat (N_1);

• at the passenger seat above the rear axle (N_2).

• At the passenger seat near the driver (N_3).

Measuring of the octave band sound pressure levels (dB) was performed within geometric mean frequencies of 31,5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz.

Results of instrumental analysis and conclusions

The results of the instrumental analysis made inside the vehicles serving the chosen regular municipal routes show the following:

1. Quantitative chemical air analysis reveals that concentration of the examined air pollutant inside the bus does not exceed one-time maximum permissible concentration of air pollutant and European Norms (WHO Standards).

2. The micro-climate parameters inside the vehicles fall within the limits of the recommended standards.

3. The artificial lighting availability inside the bus fall within the limits of the recommended standards.

4. The acoustic noise and general vibration levels do not exceed maximum acceptable level.

The further research will be aimed at evaluating the selected indicators in the spring-summer period and might reveal a seasonal dependence of the resulting values.

A promising direction is to assess the levels of acoustic noise and general vibration inside the electric omnibus.

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