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THE CHOICE AND REASONING OF THE BUS RAPID TRANSIT SYSTEMS FOR CITY TRANSPORT

Summary. The presented research is focused on the design of a new driving cycle of the Bus Rapid Transit (BRT) for the Kyiv city. This cycle consists of a complex of two types of sections. Each of them includes various phases of the traffic. A mathematical model was specified, which serves for defining the efficiency properties indices and for regimes of bus transport. The BRT are used within the bus lines. It was found, that two articles articulated buses are the most suitable choice, the MAZ-215 among them, for exploitation. At the same time, they provide the smallest fuel consumption together with the shorter operation time on the bus

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line as well as higher average speed at full and half loading. The optimal driving speeds of the steady traffic are the values of 50 km/h for section up to 1 km and 60 km/h or 70 km/h for section over 1 km. It was evaluated, that depending on the steady motion speed and the load level, the driving time of the BRT on the line varies from 20.1 min to 23.4 min, which is much lower than the driving time of a trolleybus on the same line according to the traffic schedule.

Keywords: bus rapid transit, efficiency, passenger transport

1. INTRODUCTION

The number of passenger transportation in the cities is continuously increasing. That deteriorates the efficiency of public transportation systems. This problem not only affects the city citizens who are using public transport, but also the managers and designers of the cities transport systems. The use of the bus rapid transport system (Bus Rapid Transit, BRT) will facilitate the improvement of the quality of public transport functioning by improving the quality of public transport functioning.

BRT system is a high-quality bus transport system offering a quick, comfortable and economical urban transport due to the usage of dedicated lanes that are physically separated from the roadway. The vehicle fleet normally consists of the increased capacity buses, the system of monitoring and traffic control, including the opportunity of giving buses the right of way at crossroads, measures to accelerate boarding and landing the passengers, purchasing season tickets etc.

As of the beginning of 2023, 186 cities on the six continents had implemented BRT systems that comprise 5607 km of lines and 31.5 million passengers daily. The highest number is in the Latin America countries – up to 17.5 million passengers and 62 cities [1].

It was impossible to bypass Ukraine when discussing the opportunity of implementation and functioning BRT systems. The Kyiv City State Administration (KCSA) announced the tender for the development of technical and financial justification for the BRT system in 2017. It was planned to implement the two lines to link the residential area Vyghurivshchyna-Troyeshchyna with the existing underground stations. Though this project has not been implemented, the discussions about it are still ongoing. Though this project has not been implemented, the discussions about it are still being continued.

To assess the efficiency of a functioning BRT system, selection, and reasoning its rolling stock, it is reasonable to apply mathematic modelling. This enables to determine the main operational properties of buses and the parameters of BRT system at the stage of designing in general.

2. LITERATURE REVIEW

Numerous works have been devoted to BRT system functioning, selecting its routes, and also determining operational features of the rolling stock that can be used on BRT lines.

The state of public transport in Kiev was analysed, and the route of metrobus (BRT) was suggested, connecting the residential area "Vyghurivshchyna-Troyeshchyna" and the closest underground station "Pochaina." The launch of the metrobus on this route will reduce the motion duration by 18.5 minutes.

It was conducted in the works [2, 3] determining the indexes of traction and speed properties of trailer bus trains that can be operated in BRT systems. The optimal schemes of their composing were selected. The bus train is composed of two or three single buses connected with a traction and speed device, with the possibility of connecting with one engine.

In the works [4-7], the indexes of fuel cost-effectiveness and the level of harmful substances exhausted into the environment were researched. A comparison of BRT systems and individual motorized transport conducted in the research [4] revealed that the energy consumption and emissions of carbon dioxide while transporting one passenger are significantly lower, ranging from 11% to 85% of passenger vehicle emissions. In the works [5,6] it was analysed the influence of the amount of passengers, traffic intensity, prices for fuel and usage of four different buses on the cost of transport maintenance in the BRT system of Curitiba city (Brazil) in the BRT system of Curitiba city. A three-link jointed bus and a hybrid two-axle bus plug-in were used to evaluate energy consumption, taking into account different load and driving cycles. It was established that two-link hydrid bus is the most efficient for replacement of three-link jointed buses that are currently being exploited on BRT lines in Curitiba city. A comprehensive evaluation of the impact of alcohol fuels (E100) and their mixtures (E27, E85) on buses operating on BRT lines in Fortaleza city (Brazil) was conducted in the research [7] It was shown that alcohol fuels and their mixtures are perspective for usage in BRT systems, they enable to reduce harmful substances exhausts into the environment, however they need improvement of the power flexible system (PFS).

Research of durability and manoeuvrability of buses in BRT systems was conducted in the works [8-13]. It was the improved mathematical model of the three-link road train in the work [8], that enabled to define indexes of traffic sustainability of both two-links and three-links metrobus. It was established that the sustainability of rectilinear traffic of both two-link and three-link metrobuses is provided, considering that the traffic of metrobuses is conducted along the separately allocated lanes with the velocity up to 25 to 28 m/s. Improvement of jointed buses traffic sustainability for BRT systems due to development of the new type of jointing was considered in the work [9]. In the works [10] and [11] it was considered the indexes of manoeuvrability of three-link jointed buses, and it was established that their improvement via bus composing parameters and towing links in boundary modes of traffic is, practically, impossible. Such a bus does not locate in the acceptable traffic lane regulated by Directive 2002/7/EC, and, consequently, there occurs a necessity for reconstruction of the already existing transport infrastructure for exploitation of such a rolling stock on metrobus lines. Overall traffic lane can be reduced via the usage of controlled wheels (axes) of the trailer. The research object in the mentioned works [12] and [13] are trailed road trains of different compositions that can be used in the metrobus system. It was investigated the indexes of manoeuvrability, and it was established that three-link trailed road train significantly exceeds three-link hinge-articulated bus.

3. MATERIALS AND METHODS

It is reasonable to use driving cycles that reflect real performance conditions to the fullest to assess the indexes of performance characteristics, in particular, fuel efficiency of vehicles. They consist of sequential areas including acceleration, motion with the steady velocity, retarding and engine performance in the mode of minimal frequency of idling rotation.

While mathematical modelling bus motion, it is necessary to question the average route with typical motion phases obtained from the usage of real performance data and assess it based on fuel consumption.

On purpose of improving transport provision of the residential area Vyhurivshchyna-Troyeshchyna in the city of Kyiv. Based on the analysis of the existing transport network and previous projects, it was offered to implement BRT system on the route Myloslavska Street and underground station Pochaina”. This route was selected for further modelling.

The route has a common length of 11.1 km and comprises 13 stops. The list of the stops and the distance between them is given in Table 1. The average distance between the stops comprises 854 m and fits in generally accepted norms applied at designing BRT lines (800 m to 1200 m). The distance between the stops is less than average on the area of the route passing along the residential area “Vyghurivshchyna-Troyeshchyna” (from the stop in Myloslavska Street to the stop of the residential area “Raiduzhnyi”). It relates to the necessity of providing the most convenient and close access of the residential area dwellers to the stops.

Tab. 1

Main characteristics of the route “Myloslavska Street – Underground Station “Pochaina”

Area number	Area name	Area length [m]
1	Myloslavska Street – Maryna Tsvetayeva Street	560
2	Maryna Tsvetayeva Street – Trade Centre (TC “Mayak”)	700
3	Trade Centre (TC “Mayak”) – Serzh Lyfar Street	540
4	Serzh Lyfar Street – General Store (TC “Festival”)	620
5	General Store (TC “Festival”) – Theodore Dreiser Street	620
6	Theodore Dreiser Street – Micro district №1	700
7	Micro district №1– Residential area “Raiduzhnyi”	1350
8	Residential area “Raiduzhnyi”– Shopping and entertainment centre (SEC „Skymall”)	1340
9	Shopping and entertainment centre (SEC „Skymall”) – “Muromets” park	1330
10	“Muromets” park – Supermarket (SEC “Blockbaster”)	1820
11	Supermarket (SEC “Blockbaster” – Yordanska Street	830
12	Yordanska Street – Underground Station “Pochaina”	690

The route runs from Myloslavska Street to V. Mayakovskyi Avenue, R. Shukhevych Avenue, Northern Bridge, S. Bandera Avenue to the crossing with Obolon Avenue next to underground station “Pochaina” (Figure 1) [1].

It was proposed to replicate each segment of the route by utilizing a segment of a driving cycle of one of two distinct types, each of which comprises distinct phases of traffic. The schemes of the driving cycle are reflected in Figure 2.

So, the section of Type 1 comprises: Phase 1 – stops on purpose of boarding and disembarking passengers I, Phase 2 of Acceleration II, Phase 1 of the traffic with a steady velocity III and Phase 1 of retarding IV. To the section of Type 2: Phase 1 of the stop aimed at boarding and disembarking passengers I, Phase 2 of acceleration II, Phase 2 of the traffic with the steady velocity III, Phase 2 of retarding IV and Phase 1 of the stop on the route V.

Based on the suggested areas, a driving cycle was created with 12 areas. The characteristics were given in Table 2.

The length of the cycle areas was chosen as those for the suggested route "Myloslavska Street - Underground Station "Pochaina."

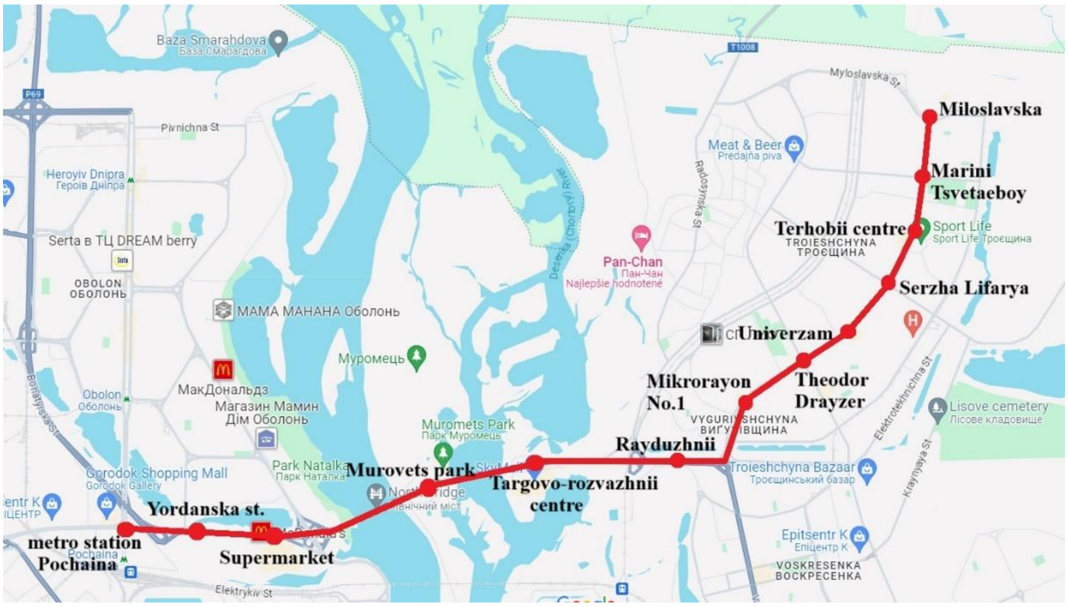


Fig. 1. The suggested route of the BRT system [1]

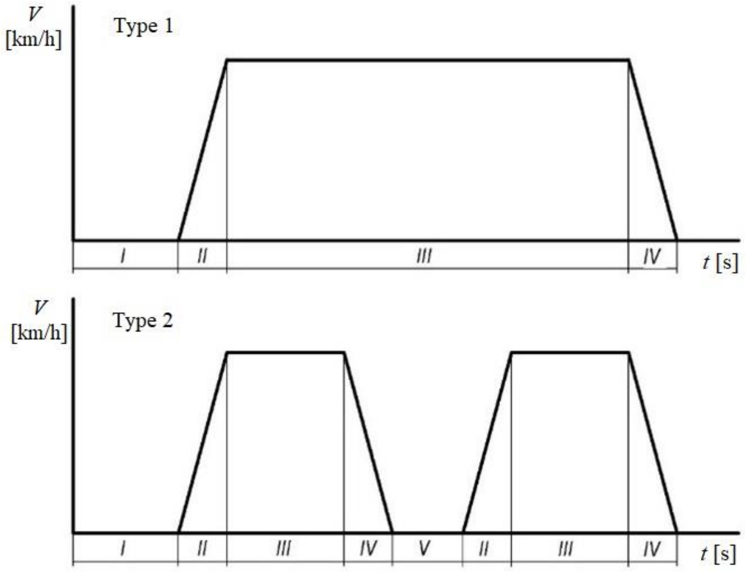


Fig. 2. Schemes of driving cycle areas: Traffic phases: I -stop for boarding and disembarking passengers; II – acceleration: III – traffic with a steady velocity – retarding until the complete stop; V -stop (in front of the traffic lights object); VI – retarding until the complete stop and acceleration to the steady traffic speed

The stop time for boarding and disembarking the passengers (Phase I) was accepted at the level of 30 s that corresponds to the average time of boarding and disembarking the passengers (20-35 s) on the existing BRT systems and underground.

The bus acceleration (Phase II) in the cycle takes place on condition of the full usage of the engine power, on purpose of the quickest transition to the steady traffic mode (Phase III).

Steady velocity of the bus traffic (Phase III) is defined on condition of the opportunity of its reaching on the route section and on condition of providing minimal fuel consumption. Steady traffic velocity was accepted within the range of 50-80 km/h in calculations. It comprised 50-60 km/h, on the sections up to 1 km long (8 stops) and on the section No. 7 (Micro District No. 1 – Residential Area "Raiduzhnyi") that implies the stop within the limits of the section, on the sections over 1 km – 50-80 km/h.

Tab. 2

Characteristics of driving cycle

No. of section	Section length [m]	Time of stop for boarding and disembarking passengers (Phase I) [s]	Stop time (Phase V) [s]	Section type of driving cycle	Steady traffic velocity [km/h]
1	560	30	0	Type 1	50, 55, 60
2	700	30	0	Type 1	50, 55, 60
3	540	30	0	Type 1	50, 55, 60
4	620	30	0	Type 1	50, 55, 60
5	620	30	0	Type 1	50, 55, 60
6	700	30	0	Type 1	50, 55, 60
7	1350	30	30	Type 2	50, 55, 60
8	1340	30	0	Type 1	50, 60, 70, 75, 80
9	1330	30	0	Type 1	50, 60, 70, 75, 80
10	1820	30	0	Type 1	50, 60, 70, 75, 80
11	830	30	0	Type1	50, 55, 60
12	690	30	0	Type 1	50, 55, 60
TOTAL	11100	360	30		

Retarding the bus (phase IV) via the engine or braking system should provide average retarding for the buses at the level of j_{sp} = 1.5 m/s^2.

Stop on the route determined by traffic phase V, imitates stop of the bus in front of the traffic lights object at the crossroads of Myloslavska Street and R. Shukhevych Avenue. The average duration of the stops in front of the traffic lights states 30 s, and therefore it is accepted in the calculations.

The main indexes that will be defined while mathematical modelling are:

1. traffic time on route section τ_i,
2. fuel consumption on route section Q_i,
3. average velocity on route section v_{cpi}.

To determine and research the indexes of performance properties of a rather complex mechanical system "automobile" and to analyze the influence of external factors on it (a driver, a road) is possible on mathematical model basing on differential equation of the rectilinear traffic [14]:

$$\frac{dV}{dt}\cdot M_a\cdot\delta_{ob}=P_{kol}(V)-P_{on}(V,V^2)\pm G_a\cdot\sin\alpha \qquad (1)$$

where M_a – complete mass of the automobile [kg], δ_{ob} – index considering rotation masses of the automobile, $P_{kol}(V)$ – complete circle force on leading wheel of the automobile [N], $P_{on}(V,V^2)$ – the sum of automobile resistance forces depending on its traffic speed [N], $G_a\cdot sin\alpha$ – lift resistance force [N], G_a – gravity from the complete mass of the automobile [N], α – angle of longitudinal inclination of the road surface [°], V – automobile traffic speed [m/s], $\frac{dV}{dt}$ – automobile acceleration [m/s^2].

Taking into consideration the fact, that the analytical function for the force $P_{kol}(V)$ is impossible to define accurately, the stated differential equation (1) of the second order with steady indexes is the equation that is not integrated in the common case. However, its integration may be conducted if we suppose that function $P_{kol}(V)$ is set or defined, for example, if we consider the engine performance according to velocity external characteristics. In this case, the solution of the equation will depend on a great number of parameters that are reasonable to split into two groups.

The first group relates to constructive automobile parameters and initial characteristics of working processes and of its outfits influencing on the final indexes of automobile traffic. The second group comprises parameters characterizing road conditions and interaction of automobile wheels and bearing surface.

The main variable in the differential equation of automobile traffic is linear traffic velocity. Due to this, all the members of its right part should be expressed relatively to the linear speed of movement for equation integration.

Thus, it is necessary to express a complete circle force and force of motion resistance via linear automobile traffic linear velocity for solving the equation of automobile traffic.

It was used the methodology suggested in the works [15-17] for defining calculation of fuel consumption in different traffic phases.

Fuel consumption, in the mode of steady motion with the constant velocity (Phase III of the cycle), is defined via dependency:

$$Q_i=k_Q\cdot Q_{oc}\cdot\tau_y\,, \qquad (2)$$

where k_Q – index of fuel consumption correction, Q_{oc} – second fuel consumption [kg/s], τ_y – time of bus traffic with steady velocity [s].

Second fuel consumption is defined:

$$Q_{oc}=a_{Qc}\cdot V^2+b_{Qc}\cdot V+c_{Qc}, \qquad (3)$$

Where

$$a_{Qc}=\frac{a_{\cdot Q}\cdot U_i^2}{3600\cdot r_k^2}\,,b_{Qc}=\frac{b_Q\cdot U_i}{3600\cdot r_k}\,,c_{Qc}=\frac{c_Q}{3600}\,, \qquad (4)$$

U_i – bus general transmission ratio on the 1st gear, r_k – wheel rolling radius [m], a_Q, b_Q, c_Q – approximation indexes of engine hourly fuel consumption function:

$$Q_o = a_Q \cdot \omega^2 + b_Q \cdot \omega + c_Q\,. \tag{5}$$

where ω – angle velocity of engine crankshaft rotation [rad/s].

On condition of availability of speed external engines characteristics, indexes a_Q, b_Q, c_Q are defined via Lagrange's interpolation formula on condition that:

$$Q_o = \frac{g_e \cdot N_e}{1000}\,, \tag{6}$$

where g_e – relative fuel consumption [g/kWh], N_e – engine power [kWh].

Finally indexes a_Q, b_Q, c_Q:

$$\begin{gathered}
a_Q = \frac{((g_N \cdot N_{\max} - g_{\min} \cdot N_{\min}) \cdot (\omega_M - \omega_{\min}) - (g_M \cdot N_M - g_{\min} \cdot N_{\min}) \cdot (\omega_N - \omega_{\min}))}{1000 \cdot ((\omega_N{}^2 - \omega_{\min}{}^2) \cdot (\omega_M - \omega_{\min}) + (\omega_{\min}{}^2 - \omega_N{}^2) \cdot (\omega_N - \omega_{\min}))} \\
b_Q = \frac{\dfrac{(g_M \cdot N_M - g_{\min} \cdot N_{\min})}{1000} + a_Q \cdot (\omega_{\min}{}^2 - \omega_M{}^2)}{\omega_M - \omega_{\min}} \\
c_Q = \frac{g_{\min} \cdot N_{\min}}{1000} - a_Q \cdot \omega_{\min}{}^2 - b_Q \cdot \omega_{\min}{}^2
\end{gathered}\,, \tag{7}$$

The highest reliability of fuel consumption at partial usage of engine power is reached at two initial graphs of dependency of torque and hourly fuel consumption from angle velocity of engine shaft speed and position of the fuel supply control body. The stated characteristic enables to establish connection between hourly fuel consumption at partial and complete fuel provision for the researched range of angle velocities of engine crankshaft. However, they may be obtained only via experimental way having defined loading characteristics of the particular engine at different frequencies of crankshaft rotation.

The index of fuel consumption correction, is introduced at defining fuel consumption, on condition of partial usage of engine power $k_{Q,}$ defined as:

$$k_Q = a_{ki} \cdot k_i^2 + b_{ki} \cdot k_i + c_{ki}\,, \tag{8}$$

where k_i – index of engine power usage: a_{ki}, b_{ki}, c_{ki} – function approximation indexes $k_Q = f(k_i)$.

Index of engine power usage for defining fuel efficiency indexes [16]:

$$k_i = \frac{M_a \cdot g \cdot (f_0 + K_f \cdot V) + K_B \cdot F \cdot V^2}{A_i \cdot V^2 + B_i \cdot V + C_i}\,, \tag{9}$$

where M_a – complete bus mass [kg], f_0 – index of rolling resistance at low traffic speeds, K_f – index considering alteration of rolling resistance at traffic speed increase, ρ – air density [kg/m^3], C_x – aerodynamic resistance index, F – frontal area [m^2], A_i, B_i, C_i – approximation indexes of circle force equation:

$$A_i = a\cdot\frac{U_i^3\cdot\eta_m}{r_b\cdot r_k^2},\ B_i = b\cdot\frac{U_i^2\cdot\eta_m}{r_b\cdot r_k},\ C_i = c\cdot\frac{U_i\cdot\eta_m}{r_b}, \tag{10}$$

where η_m – transmission efficiency index, r_b and r_k – dynamic radius and wheel rolling radius [m], a, b, c – approximation indexes of engine torque obtained in the experimental way:

$$\begin{aligned} a &= \frac{M_N - M_{\kappa.\min} - \dfrac{M_{\kappa.\max} - M_{\kappa.\min}}{\omega_M - \omega_{\min}}\cdot(\omega_N - \omega_{\min})}{\omega_N{}^2 - (\omega_M + \omega_{\min})\cdot\omega_N - \omega_{\min}{}^2 + (\omega_M + \omega_{\min})\cdot\omega_{\min}} \\ b &= \frac{M_{\kappa.\max} - M_{\kappa.\min}}{\omega_M - \omega_{\min}} - a\cdot(\omega_M + \omega_{\min})\cdot\omega_{\min} \\ c &= M_{\kappa.\min} - a\cdot\omega_{\min}{}^2 - b\cdot\omega_{\min} \end{aligned} \tag{11}$$

where ω_{min}, $M_{\kappa.min}$ – minimal angle velocity of engine crankshaft [rad^{-1}] and torque [Nm] at this angular speed, $M_{\kappa.max}$, ω_M – maximal engine torque [Nm] and engine crankshaft angular speed [rad^{-1}] corresponding to it, M_N, ω_N – torque [Nm] and angular velocity of engine crankshaft [rad^{-1}] corresponding to its maximal power.

Time of bus traffic τ_i with steady velocity is the ratio of the difference between the overall length of route section S_i, acceleration way S_{pi} and braking S_{ri} on this section up to the steady traffic velocity v_i.

Traffic time of the bus τ_i with steady velocity:

$$\tau_i = \frac{S_i - S_{pi} - S_{ri}}{v_i}. \tag{12}$$

Acceleration way S_{pi} is defined via dependency:

$$S_{\mathrm{pi}} = M_a\delta_{ob}\int_{V_n}^{V_\kappa}\frac{VdV}{a_iV^2 + b_iV + c_i}. \tag{13}$$

where δ_{ob} – index considering rotation bus masses, V_n, V_κ – initial and final bus traffic velocities [m/s], a_i, b_i, c_i – indexes of the right part of differential equation of bus motion [14]:

$$\begin{aligned} a_i &= A_i - 0{,}5\cdot\rho\cdot C_x\cdot F, \\ b_i &= B_i - K_f\cdot M_a\cdot g, \\ c_i &= C_i - f_0\cdot M_a\cdot g \end{aligned} \tag{14}$$

Braking way is defined as:

$$S_{ri} = \frac{(V_n - V_\kappa)^2}{2 \cdot j_{cn}}, \tag{15}$$

where V_n, V_κ – initial and final bus traffic velocities [m/s], j_{cn} – bus retarding [m/s^2].

Fuel consumption at non-steady motion at full use of engine power (Phase II and part of Phase IV of the cycle) corresponding to the bus modes, is defined via dependency:

$$Q_i = M_a \cdot \delta_{ob} \cdot \int_{v_n}^{v_\kappa} \frac{a_{Qc} \cdot V^2 + b_{Qc} \cdot V + c_{Qc}}{a_i \cdot V^2 + b_i \cdot V + c_i} dV. \tag{16}$$

Acceleration time is defined by dependency:

$$\tau_{pi} = M_a \cdot \delta_{ob} \cdot \int_{V_n}^{V_\kappa} \frac{dV}{a_i \cdot V^2 + b_i \cdot V + c_i}. \tag{17}$$

Fuel consumption of the bus while its engine idle performance (Phases I and V of the cycle) Q_{xx} is defined from the hourly fuel consumption equation (2.4) on condition of the set time of engine performance on:

$$Q_{xx} = k_{xx} \cdot \left(a_Q \cdot \omega_{xx}{}^2 + b_Q \cdot \omega_{xx} + c_Q\right) \cdot \frac{\tau_{xx}}{3600}, \tag{18}$$

where ω_{xx} – rotation frequency of idling speed of the engine [rad/s], τ_{xx} – time of idling engine performance [s], k_{xx} – correction index [16].

Fuel consumption, in the modes of bus retarding (Phase IV of the cycle) while braking (by the engine, or working braking system), is accepted as while engine performance in idling performance mode as in modern power supply systems of diesel fuel supply in the modes of forced idle mode up to certain frequency of crankshaft rotation (1000-1600 min^{-1} depending on the engine type) and bus engine velocity is missing, and in the future, is close to fuel consumption in the idle mode and is determined by second fuel consumption considering bus braking time on *i* section of the route τ_{ri}:

$$Q_{ri} = k_{xx} \cdot \left(a_Q \cdot \omega_{xx}{}^2 + b_Q \cdot \omega_{xx} + c_Q\right) \cdot \frac{\tau_{ri}}{3600}, \tag{19}$$

where τ_{ri} – braking time [s].

Braking time τ_{ri} is defined via dependency:

$$\tau_{ri} = \frac{V_n - V_\kappa}{j_{cn}}. \tag{20}$$

Finally, fuel consumption while performing the suggested driving cycle by the bus, is the sum of fuel consumption on *i* sections of driving cycle, kg:

$$Q_{\Sigma} = \sum Q_i \,. \tag{21}$$

The following dependency is used for exchanging diesel fuel consumption from kilograms into liters:

$$Q = \frac{Q_{\Sigma}}{\rho_b}\,, \tag{22}$$

where ρ_b – diesel fuel density [kg/l].

To compare fuel consumption of the buses with different complete masses different passenger capacity, it was offered to define fuel consumption per one passenger according to dependency, l/100 km:

$$Q_{\Pi} = \frac{Q}{n}\,, \tag{23}$$

where n – number of passengers at full loading [number of people].

Traffic time on each section of the cycle consists of the sum of traffic time on each phase of the cycle, s:

$$\tau_i = \tau_{pi} + \tau_{yi} + \tau_{ri} + \tau_{xxi} \,. \tag{24}$$

Finally, the time of performing the suggested driving cycle by the bus, is the sum of traffic time on its *i* sections of driving cycle:

$$\tau_{\Sigma} = \sum \tau_i \,. \tag{25}$$

Average traffic velocity on each route section is defined as:

$$V_{cp} = \frac{S_s}{\tau_i}\,. \tag{26}$$

Average traffic velocity in the suggested driving cycle:

$$V_{cp} = \frac{S}{\tau_{\Sigma}}\,. \tag{27}$$

The buses of especially large class (15 to 18.5m) are used, mostly in BRT systems. However, it is not uncommon to use buses with a length of 22, 24 and 25 meters.

The analysis of existing bus constructions used on BRT lines all over the world gives the reasons to classify them according to the following characteristics [18]:

1. By the length: as a rule, these are 18, 23, 24 or 25-meter buses;
2. By the number of links: 1-link (12-15 m long), 2-link (18 m long) and 3-link buses (23, 24 and 25 m long);
3. By number of axes: 3,4 or 5-axis buses:
4. By the floor height: low floor, partly low floor and high floor;
5. By engine type: diesel, natural gas NPG, hybrid (with diesel and electric motors), fully electric with autonomous run, or electric with external current source (trolleybuses) or electric with combined energy supply (autonomous run and external power supply).

It is the most reasonable to use series 2-link buses 18–19 meters long, with the further perspective of using 3-link buses on the suggested BRT route Myloslavska Street – Underground Station “Pochaina”.

Such jointed buses as LAZ-A291, LAZ-A292, MAZ-105 and MAZ-215 are in service of ME “Kyivpasstrans”.

However, considering the fact that LAZ-291 and MAZ-105 are outdated models, and they have not been issued since 2005 and 2014 accordingly, they will not participate in the further consideration.

Therefore, buses LAZ-A292 and MAZ-215 were selected as research objects that replaced the previous models (LAZ-291 and MAZ-105) on the conveyer.

Calculation results of the buses' performance properties indexes MAZ-215 and LAZ-A292 in the suggested driving cycle were equipped to the complete mass (28,000 kg) and equipped mass with half loading (22,300 kg) in Tables 3 and 4, and also Figure 3 to Figure 5.

Tab. 3

Calculation results of the indexes of performance properties of the buses MAZ-215 and LAZ- A292 in the suggested driving cycle for the complete mass (28,000 kg)

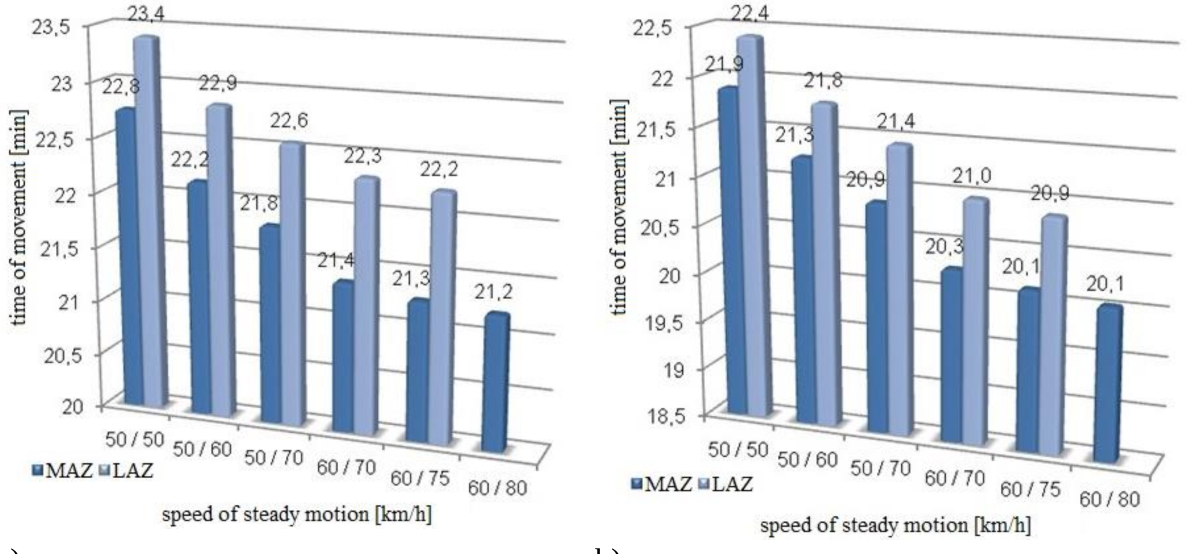
Steady traffic speed on the sections [km/h]		Time [s]		Time [min]		Fuel consumption [l/100 km]		Average speed [km/h]	
1-7, 11-12	8-10	MAZ	LAZ	MAZ	LAZ	MAZ	LAZ	MAZ	LAZ
50	50	1,365.554	1,404.644	22.759	23.411	48.827	50.959	29.263	28.448
50	60	1,329.286	1,370.994	22.155	22.85	50.574	52.959	30.061	29.147
50	70	1,308.802	1,353.834	21.813	22.564	52.765	55.295	30.532	29.516
60	70	1,282.241	1,338.682	21.371	22.311	58.299	61.233	31.164	29.85
60	75	1,276.42	1,334.915	21.274	22.249	59.593	62.278	31.306	29.934
60	80	1,273.502	-	21.225	-	60.69	-	31.378	-

Tab. 4

The calculation results of performance properties indexes of the buses MAZ-215 and LAZ- A292 in the suggested driving cycle for equipped mass with half loading (22,300 kg)

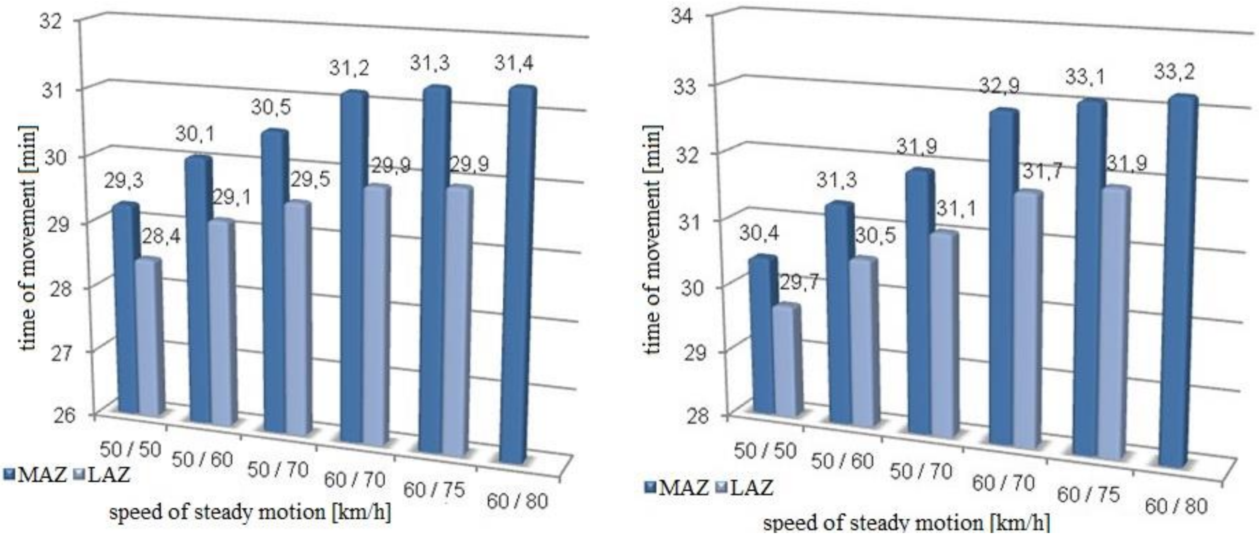
Steady traffic speed on the sections [km/h]		Time [s]		Time [min]		Fuel consumption [l/100 km]		Average speed [km/h]	
1-7, 11-12	8-10	MAZ	LAZ	MAZ	LAZ	MAZ	LAZ	MAZ	LAZ
50	50	1,313.645	1,344.866	21.894	22.414	40.241	41.568	30.419	29.713
50	60	1,275.115	1,308.135	21.252	21.802	41.779	43.369	31.338	30.547
50	70	1,251.705	1,286.925	20.862	21.449	43.678	45.556	31.924	31.051
60	70	1,215.849	1,258.764	20.264	20.979	48.33	50.905	32.866	31.745
60	75	1,208.221	1,252.439	20.137	20.874	49.459	51.97	33.073	31.906
60	80	1,203.021	-	20.05	-	50.513	-	33.216	-

Having analysed the data of Tables 3 and Table 4 shown in Figure 3 to Figure 5. It was established that the most reasonable is the bus MAZ-215 for exploitation on BRT route as it provides less fuel consumption at a smaller traffic time on the route and higher average velocity at both complete and half loading. Thus, fuel consumption for the bus MAZ-215, at steady traffic velocities of 50 km/h for the sections up to 1 km long and 60 km/h for the sections over 1 km. With complete loading is smaller by 4.5%, time of traffic on the route is by 3% lower, and the average velocity is 2.6 % higher.



a) b)

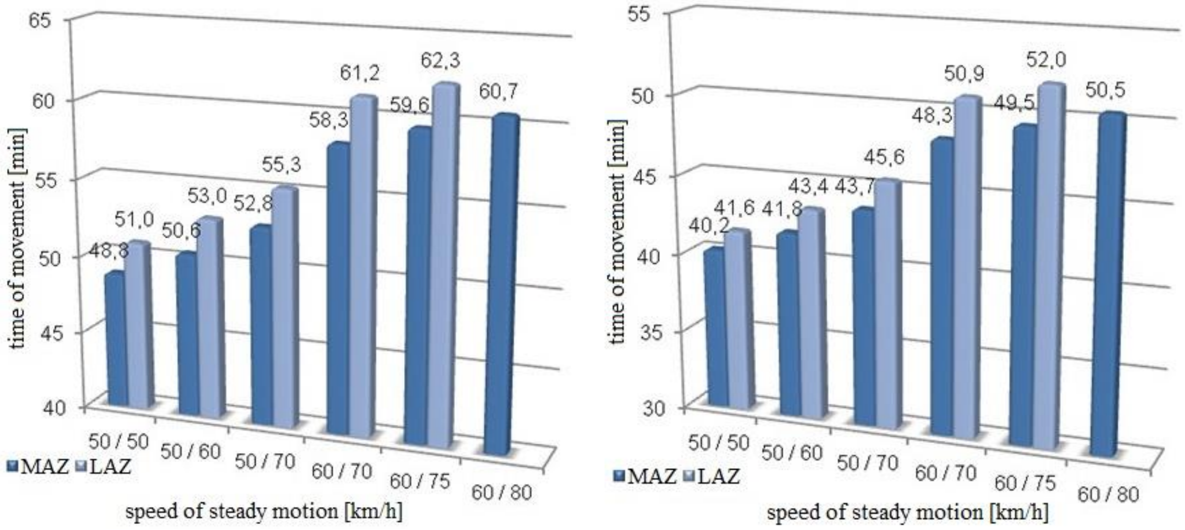
Fig. 3. Time of driving cycle performance by the buses MAZ-215 and LAZ- A292: a) for the full mass (28,000 kg); b) for equipped mass with half loading (22,300 kg)



a) b)

Fig. 4. Average traffic velocity in driving cycle of buses MAZ-215 and LAZ-A292:
a) for full mass ((28,000 kg); b) for equipped mass with half loading (22,300 kg)

Besides, it was established that increasing steady traffic velocity causes reduction of performance time suggested driving cycle and increasing average traffic velocity and fuel consumption. The most optimal velocities of steady traffic are 50 km/h for sections up to 1 km long and 60 or 70 km/h for sections over 1 km long. At the same time, the best indexes of performance properties are provided. Increasing velocities of steady traffic up to 60 (section up to 1 km long) is not reasonable as for the bus MAZ-215 with complete loading. Such velocity increase causes increasing fuel consumption by 20%. At the same time, route performance time decreases by 4.2% and the average velocity increases by 4.4% compared to steady traffic velocities 50 and 60 km/h. Fuel consumption increases by 20.9% at half loading, decreases by 5.7% and average velocity decreases by 6%.



a) b)

Fig. 5. Fuel consumption in driving cycle MAZ-215 and LAZ- A292:
a) for the full mass (28,000 kg); b) for equipped mass with half load (22,300 kg)

The time of traffic on the offered BRT route depending on velocities of the steady motion and the level of load alters within the range of 20.1 to 22.8 min for the bus MAZ-215 and 20.9 to 23.4 min for LAZ- A292. That is significantly lower than on Trolleybus 30 (Kadetskyi Hai Street – Myloslavska Street) that passes the same route for 30 min. according to the traffic schedule and without consideration of traffic influence. Besides, having reduced the boarding time from 10s until 20s (that corresponds to the time of passengers boarding disembarking in the underground), it is possible to reduce the traffic time by more than 2 min.

4. CONCLUSIONS

It was developed based on the proposed BRT route in Kyiv city, a new driving cycle consisting of sections of two types. Each of them consists of different phases of traffic, and a mathematical model was specified for defining the indexes of performance properties and modes of bus traffic used on the BRT line. It was determined that two-link jointed buses, among them MAZ-215, are the most reasonable for exploitation, and provide a smaller fuel consumption at a smaller traffic time on the route. They also provide a higher average velocity on both full and half loading. The most optimal velocities of the steady traffic is 50 km/h for sections up to 1 km and 60 or 70 for sections over 1 km. It was shown that the time on BRT route depending on the velocities of the steady motion and level of congestion alters in terms of 20.1-23.4 min. that is much lower than the time of the trolleybus passing the same route for 30 min according to the traffic schedule without considering traffic influence.

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