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ESTIMATION OF FUEL CONSUMPTION IN STANDARD DRIVING CYCLES AND IN REAL BUS OPERATION

The object of research is the basic fuel consumption of a bus in standard urban cycles and identical conditions in real operation.

Standard driving cycles are used to estimate fuel consumption. This allows consumers to compare buses and choose the best one, and manufacturers in the process of improving buses also allow them to estimate fuel consumption. However, sometimes standards may not correspond to reality. Therefore, specific routes are developed for some cities, which requires significant development costs. This problem is solved by collecting reliable information on average fuel consumption with an operating period of 1 year and bus mileage of 40–90 thousand km. As a rule, operating organizations do not provide such information. The development of electronic control systems allows to obtain information from "black boxes" additionally installed by the manufacturer, which record information throughout the entire service life of the bus. This approach is implemented in this work.

Existing standards for determining fuel consumption in urban driving cycles are presented. The results of modeling and real tests are presented. Information was collected from the "black boxes" on fuel consumption on 12 buses for 1 year of operation with mileage from 40 to 90 thousand km on Ataman A092N6 buses. Fuel consumption was 16.4–21.2 l/100 km when operating buses in one city (the manufacturer claims up to 23 l/100 km). This makes it possible to solve the problem of collecting reliable information on fuel consumption based on year-round operation of buses, which has not been carried out in this format before.

The results of this study will allow operating organizations to see the real fuel consumption on Ataman A092N6 buses in the city. Implementation of this approach on other buses will allow obtaining data for interested organizations in a similar way. This will allow estimating fuel consumption without additional tests, which will reduce research costs.

Keywords: *fuel consumption by buses, driving cycles, road tests, passenger transportation, urban cycle.*

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1. Introduction

Fuel consumption is estimated using standard test driving cycles. Such cycles allow to estimate fuel consumption under standardized conditions. Accordingly, comparing the fuel consumption of certain cars or buses, it is possible to give preference to the best in terms of fuel economy. In addition, for operating organizations back in the days of the USSR in Ukraine and all other countries, fuel consumption was written off based on data calculated according to the GOST 20306-90 standard. However, operating conditions at that time in modern cities in the former USSR differ significantly and such results cannot be used to adequately estimate linear fuel consumption. Therefore, in Ukraine, the Ukrainian Institute of Bus and Trolleybus Construction (JSC "Ukrbusprom", Lviv) developed a draft standard in 2012 that would bring fuel consumption standardization using driving cycles closer to the realities of operation. However, such a standard was not implemented. Over time, operating conditions change depending on traffic density and the development of urban infrastructure. It is also possible to use foreign standards for fuel consumption standardization: European, American, Chinese, Australian or Japanese test driving cycles. In order to approximate the results of bus tests in urban driving cycles, richer cities of the European Union (EU) countries allow developers to order a driving test cycle for their city. Or even over time to reorder/refine the driving cycle to the changed realities of operation in such cities. In particular, in the Federal Republic of Germany, the cities of Braunschweig and Aachen have such driving cycles that are developed for them. This option can maximally approximate the fuel consumption standardization to the realities of operation. However, in today's conditions, operating organizations of both state and private ownership need methods for assessing fuel consumption on specific routes and with maximum accuracy in accordance with operating conditions [1]. In particular, the same bus on different routes with the same mileage can consume different amounts of fuel, not to mention compliance with the most accurate test cycle. Thus, a prerequisite has arisen for creating more accurate methods for estimating fuel consumption on a specific route. One such method may be the installation of GPS trackers that read information from the flow meter located in the bus's fuel tank. However, such a method may be vulnerable and not 100 % insured against unauthorized interference by third parties. Therefore, the assessment of fuel consumption should be based on long-term operation (1 year) using standard means of accumulating information on fuel consumption, when dismantled, the bus, for example, may go into emergency mode. In this case, unauthorized penetration into the system is impossible and the reliability of the information obtained will be ensured. The results of such studies are needed in practice, because this will allow to plan fuel costs precisely according to a specific route.

In Ukraine, until 2022, a single standard, GOST 20306-90 [2], was in effect, which allowed for the assessment of fuel consumption of buses in the urban driving cycle. However, this standard [2] was developed back in the eighties of the last century and corresponded to the operating conditions at a time when the intensity of traffic in cities was much lower. Accordingly, the fuel consumption in such a cycle [2] turned out to be different compared to the realities of operation. Today, Ukraine does not have any current standards that would allow for the assessment of the linear fuel consumption of buses in the urban driving cycle. Therefore, in 2012, the Ukrainian Institute of Bus and Trolleybus Construction (JSC "Ukrbusprom", Lviv) proposed a new test urban cycle [3]. Accordingly, a draft of a new standard was developed. However, such a standard has not yet been implemented in Ukraine. Instead, the State Enterprise "State Motor Transport Research and Design Institute" (SE "DerzhavtotransNDIproekt", Kyiv) developed Methodological Recommendations for Fuel Consumption Standardization [4] in 2023. However, nothing is said here [4] about obtaining the basic linear fuel consumption rate (in l/100 km), which is the main component of calculating the standard fuel consumption (in l).

The paper [5] compares the test results of the "Bogdan" A231 city bus with statistical data on fuel consumption of the same buses in the Kyivpastrans Enterprise. It turned out that the fuel consumption obtained during tests according to GOST 20306-90 was 46.1 l/100 km. And during real operation, fuel consumption turned out to be lower and amounted to 42.5 l/100 km, which also coincides with the fuel loss determined using the new design of the driving cycle [3] developed by JSC "Ukrbusprom". Similar results were obtained during testing of the Bogdan A144 and Bogdan A145 buses – fuel consumption was overestimated by 10–15 % during testing according to GOST 20306-90. According to the new DSTU project, the difference in consumption compared to real operation was only 3 % [5].

The paper [6] provides an overview of various foreign standards and test cycles for determining emissions of harmful substances and fuel consumption. Cycles for buses that have a number of features and cannot be universal for any operating conditions, including in Ukrainian cities, are also provided here.

The fuel consumption test [7] can be used in accordance with the recommended practices SAE J1264, SAE J1252, SAE J1321 and SAE J2966. The document [7] describes a fuel consumption test procedure based on data collection and statistical analysis to determine the difference in fuel consumption between vehicles. It can also be used in the comparative assessment of fuel consumption of city buses.

In [8], fuel consumption test cycles and SORT cycles using computer simulations, which are commonly used for buses, are described. Statistical data for computer simulations were obtained based on real operating conditions, and the adequacy of the developed model was confirmed. Then, further studies were carried out using the verified model. All this indicates the inherent need for road tests. However, to save money, the main part of the tests is already performed using computer simulations.

In [9], the issue of bus operation in different climatic, road and transport conditions are considered. According to [8], for a correct assessment of fuel consumption by a bus in a city, it is advisable to accumulate statistical data based on driving cycles during the year.

In [10], the influence of passenger traffic, road class and road load level on fuel consumption and emissions of a city bus was studied. This approach allows to some extent to increase the approximation of the experiment to the realities of operation. However, there are a significant number of factors that are not taken into account in this study [10].

In [11], it is indicated that many driving test cycles involve acceleration of the bus at full fuel supply and deceleration at the level of emergency braking, in particular, and [2]. Therefore, in [11] a test of a bus with a diesel engine was implemented, the acceleration and deceleration modes of which correspond to real, rather than extreme, operating conditions. This approach [11] will allow to increase the identity of the driving cycle to real operating conditions.

In [12], the results of testing of urban electric buses in the SORT test cycle are presented. The methodology and the results obtained in [12] are relevant in the transition of urban transport to transport with zero carbon dioxide emissions, which should also be taken into account when developing test cycle standards for cities in Ukraine.

In [13], an analysis of the operation of buses in the city of Rzeszow (Poland) on the selected route to determine energy consumption in real operating conditions using GPS trackers. This approach allowed to estimate the share of energy consumption associated with bus stops. However, the use of trackers can sometimes be unsafe from unauthorized interference and affect the reliability of the research results.

In work [14], a dependence was obtained based on statistical data on bus traffic on city routes and its adequacy was checked. Using the obtained dependence, the fuel consumption of the bus was estimated both on individual runs and on a certain section of the route, which allows to bring the research results closer to the realities of operation.

In work [15], the feasibility and results of a one-year study of energy consumption by city buses in Poland are substantiated and presented. Such justification [15] confirms the feasibility of conducting one-year fuel consumption tests on a specific route. This will allow to accumulate statistical data for the possibility of standardizing fuel consumption on a specific route.

In [16], computer simulation of city bus routes was carried out, taking into account downtime at stops for boarding and disembarking passengers. Such a study takes into account the simulation of traffic based on accumulated statistical data of operation in similar conditions to the simulation. This confirms the need to collect statistical data on specific operating conditions. However, the collection of statistical information requires significant time and energy resources.

The authors of [17] propose a Markov chain-based method for synthesizing naturalistic driving cycles with a high sampling rate based on route segment statistics obtained from vehicle tracking data with a low sampling rate. In the case of the urban bus transport system, the route segments correspond to the sections between two consecutive bus stations. This approach could be useful in forming test driving cycles. All this allows to state that there are not so many test cycles in the world for determining the fuel consumption of a bus when transporting passengers in a city. In addition, each country has its own transport infrastructure characteristics, so each test standard may be suitable for a specific state. In addition, in the USA and Germany, there was a need to develop a test cycle for a specific city, since within the same state cities have different population densities, respectively, passenger flow, road capacity, etc. And in Ukraine there is no such standard at all. Although in 2012, an adequate test cycle project for implementation was presented to JSC "Ukrbusprom". As the realities of the application of test cycles show, over time, such projects require periodic refinement due to changing bus traffic conditions in cities, on the one hand. On the other hand, each test cycle is necessarily compared with the realities of operation. Therefore, it is advisable to conduct a study dedicated to obtaining real data on fuel consumption of buses in the city, which will ensure reliable results and prevent falsification of data by both the operating organization and drivers directly on the route. Such an idea will be implemented today by modern electronic memory units, which should be an integral part of the bus's electronic network (the so-called "black box").

The aim of research is to develop an approach to assessing fuel consumption by public transport buses taking into account world standards and monitoring fuel consumption on real routes. This will make it

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possible to assess fuel consumption, taking into account global experience and the existing regulatory framework, using modern methods of controlling fuel consumption in the background and without unnecessary intervention during information accumulation.

2. Materials and Methods

The object of research is the basic fuel consumption of a bus in standard urban cycles and identical conditions in real operation.

The main hypothesis of research is that with the existence of a large number of regulatory acts, the basic option for fuel consumption of buses when transporting passengers in urban conditions is statistical information on fuel consumption for one year. Statistical data based on year-round operation allow to take into account the change in ambient temperature during the year, passenger flow and taking into account the operating conditions of buses during peak hours and interpeak intervals.

Information on fuel consumption is collected based on statistical data on year-round operation of Ataman A092N6 buses when transporting passengers in the city. Considering that this bus is built on the Japanese Isuzu aggregate base, the high development of Japanese technologies allows to introduce advanced electronic systems into the design of the machine set. To collect statistical data on fuel consumption on city buses "Ataman" A092N6, it was proposed to use the optional in the past, and now the standard Mymemory unit (the so-called "black box"). Using the standard Mymemory unit allows to accumulate statistical information without the participation of the operating organization. Fuel consumption is calculated not by the fuel level sensor, but by the cyclic fuel supply, which is calculated by the electronic engine control unit. This algorithm for collecting statistical information allows to directly determine the amount of fuel supplied to the engine combustion chambers and ignores fluctuations in the level in the fuel tank: refueling, refueling, unauthorized draining, etc. In addition, the Mymemory unit is integrated into the vehicle's electronic system via the CAN bus in such a way that if it is unauthorizedly disconnected, the bus goes into emergency mode. The integrated memory unit (Mymemory unit) in the electronic system provides continuous information collection, unlike additional equipment using GPS monitoring and collecting information on fuel consumption based on a sensor in the fuel tank.

After a year of operation of the Ataman A092N6 buses, when transporting the bus in the city, information is downloaded from at least ten buses within one motor transport enterprise. A special diagnostic device G-IDSS [18] is connected to each Ataman A092N6 bus, which has full access to the Mymemory unit (only the manufacturer has such functionality) and a personal computer (PC) such as a laptop with licensed software (Fig. 1).

Fig. 1. Application of the G-IDSS device when reading information from the Mymemory unit on the "Ataman" A092N6 bus

First, a set of parameters for downloading information is set, and then a file in pdf format is saved to the internal memory of the PC. For this, the following information is sufficient to determine the average fuel consumption: total mileage (in km) and total fuel consumption (in l/100 km). Then the measurement results are processed and the average fuel consumption is determined based on data collected from all buses used to collect information.

The representativeness error is determined by the formula:

$$\Delta = \frac{\sigma}{\sqrt{n}}, \quad (1)$$

where n – number of measurements; σ – standard deviation;

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}}, \quad (2)$$

where X_i – i-th option; $\overline{X}$ – arithmetic mean;

$$\overline{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}. \quad (3)$$

The variance is determined by the formula:

$$D = \sigma^2. \quad (4)$$

After that, the results of real operation are compared with the fuel consumption study data in a specific driving cycle and a decision is made on the compliance of the standard driving cycle with the operating conditions.

3. Results and Discussion

3.1. Analysis of existing world standards for estimating fuel consumption by buses in standardized driving cycles and selection of a rational method

The HWFET test (Fig. 2) involves estimating fuel consumption of buses on the highway, however, it does not provide for measuring fuel consumption in the city [6].

The FTP transient test [6] (Fig. 3) is used to evaluate the fuel consumption of both trucks and buses. It includes segments designed to simulate both city and highway driving. It is used for certification tests for diesel engine emissions and fuel consumption in the USA [6]. A feature of this FTP transient test [6] is that it is designed to conduct tests using a brake test bench.

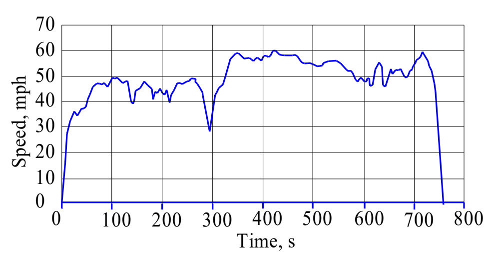

Fig. 2. HWFET test [6]

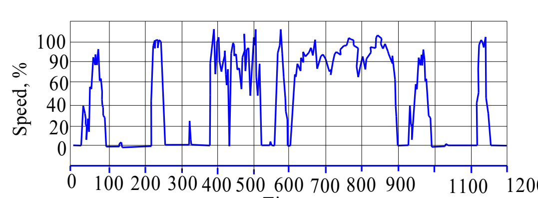

Fig. 3. FTP transient test [6]

The New York Bus (NYBus) cycle [6] (Fig. 4) is a test that reflects real-world bus driving patterns in New York City (USA), but may not be appropriate for other cities.

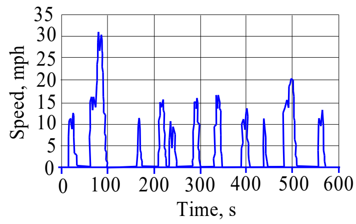

Fig. 4. New York Bus cycle [6]

The Manhattan cycle [6] (Fig. 5) was developed based on actual observed driving patterns of city buses in midtown Manhattan, New York. The cycle is characterized by frequent stops and very low speeds. But again, the Manhattan cycle will only correspond to the specified operating conditions in a particular city.

The Orange County Bus (OC BUS) cycle [6] (Fig. 6) was developed by West Virginia University (WVU) based on the driving patterns of city buses in the Los Angeles, California area. This cycle also corresponds to specific driving conditions and is not a universal test cycle.

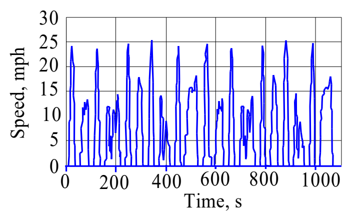

Fig. 5. Manhattan cycle [6]

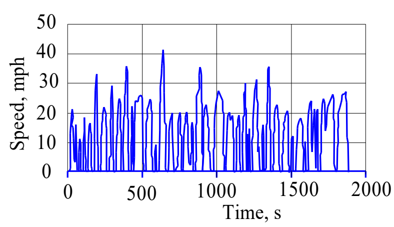

Fig. 6. Orange County Bus cycle [6]

The following cycles are used in EU countries. Common Artemis Driving Cycles (CADC) [6] are test cycles developed within the framework of the European Artemis project (Assessment and Reliability of Transport Emission Models and Inventory Systems). This cycle is based on statistical analysis of a large database of European driving models in real road conditions. The cycles include three traffic schedules: urban (Fig. 7), rural road and motorway. The "Motorway" cycle has two variants with a maximum speed of 130 and 150 km/h. This approach in the CADC cycle [6] allows to take into account the realities of operation when forming standard test cycles, however, the realities of operation of urban and other classes of buses are not taken into account here.

The ETC test cycle [6] was introduced, together with the ESC (European Steady State Cycle), for the certification of diesel engine emissions in Europe starting with the Euro 3 standard (2000) (Directive 1999/96/EC of 13 December 1999). The ESC and ETC cycles replaced the earlier R-49 test and were used for the certification of engine emissions to Euro 5. The Euro 6 emission standards (2013) replaced ESC/ETC with the WHSC/HYPERLINK test cycles, respectively. The ETC cycle (formerly also known as the FIGE Transition Cycle) was developed by the former FIGE Institute in Aachen, Germany (Fig. 8), based on real-world driving cycle measurements. The final ETC cycle is a shortened and slightly modified version of the original FIGE proposal. Different driving conditions are represented by three parts of the ETC cycle, including urban, rural and motorway driving. The duration of the entire cycle is 1800 s. The duration of each part is 600 s. However, this cycle (ETC) is not designed to determine fuel consumption during testing.

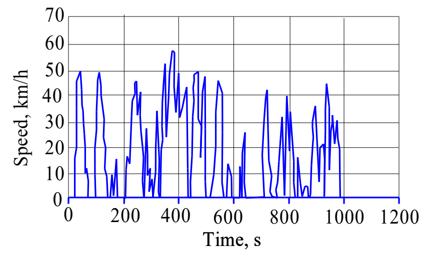

Fig. 7. Common Artemis Driving Cycle [6]

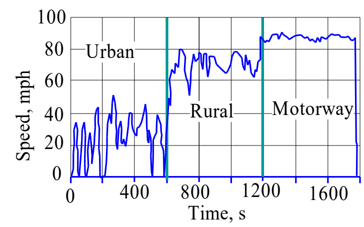

Fig. 8. FIGE cycle, developed by the former FIGE Institute in Aachen, Germany [6]

The Braunschweig City Driving Cycle [6] was developed at the Technical University of Braunschweig (Braunschweig, Germany) (Fig. 9). It is a transient driving schedule that simulates the driving of a city bus with frequent stops. The cycle is performed on a dynamometer. The Braunschweig cycle has been frequently used in various research projects, as well as in some equipment certification programs. With the introduction of the transient ETC cycle, the role of the Braunschweig cycle has diminished. Comparative studies have shown that the ETC accounts for approximately 40 % lower power output and 30–70 % lower regulated emissions than the Braunschweig cycle. All other cycles in the EU do not provide for the determination of fuel consumption specifically for buses in the urban driving cycle, since the main focus is on environmental performance mainly for trucks with diesel engines.

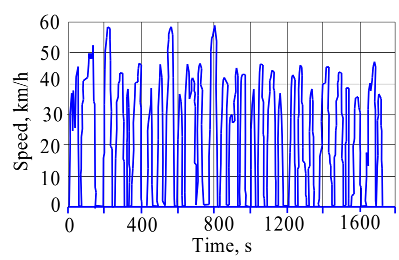

Fig. 9. Braunschweig cycle [6]

Japan provides for the use of test driving cycles taking into account the characteristics of operation [6]. The Japanese six-mode cycle [6] was used in Japan for testing cars and buses with large displacement engines. It has been replaced by the newer thirteen-mode cycle and is of historical significance only. The engine was tested at six different speed and load modes. The modes were run sequentially, and the duration of each mode was 3 min. Emissions were measured at each mode and averaged over the cycle using a set of weighting factors. The final test result was expressed as a volumetric concentration (in ppm). There were two definitions of test modes and weighting factors: one for diesel engines and the other for gasoline and LPG engines. The tests using the six- and thirteen-mode cycles do not include measurement of fuel consumption of buses. Subsequently, the thirteen-mode cycle was replaced by the Japanese JE05 cycle (Fig. 10).

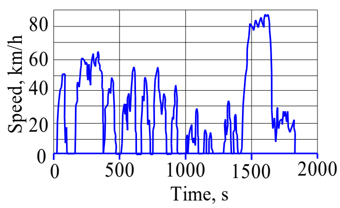

Fig. 10. Japanese JE05 cycle [6]

There are many cycles in China to determine the linear fuel consumption of vehicles, including city buses [6]. The China Heavy Commercial Vehicle Test Cycle is part of the China Automotive Test Cycle (CATC) developed by the China Automotive Technology and Research Center (CATARC). The CHTC is defined by the national standard GB/T38146.2, China Automotive Test Cycle Part 2: Heavy-duty Commercial Vehicles, issued in October 2019 and applicable from May 2020. The CHTC replaced the C-WTVC (a modified version of the WHVC) for the purpose of vehicle certification. The CHTC includes six dynamometer cycles for various types of heavy commercial vehicles with a gross vehicle weight of more than 3,500 kg. One of the six is the China City Bus Test Cycle (CHTC-B) (Fig. 11). This cycle (CHTC-B) [6] is one of the few cycles that is directly relevant to measuring the fuel consumption of buses in the urban driving cycle. However, bus driving regimes in Chinese cities differ significantly from those in EU countries and Ukraine.

In Australia, the development of the Composite Urban Emissions Driving Cycles (CUEDC) was commissioned by the Australian National Environment Commission in 1998 as part of the National Diesel Environmental Action. Data were collected in Sydney, Australia [6] (Fig. 12).

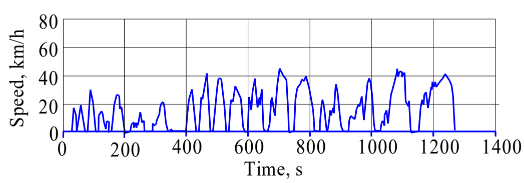

Fig. 11. CHTC-B test cycle for city buses [6]

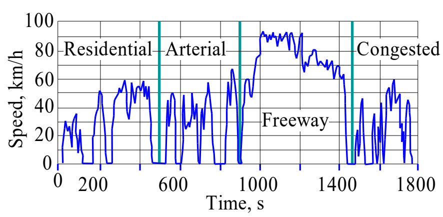

Fig. 12. Gasoline CUEDC cycle [6]

Different CUEDCs have been developed for each of the main categories of diesel-powered vehicles, from off-road passenger cars and light trucks to heavy-duty road trains. There are six CUEDC cycles, one for each of the six ADR vehicle categories: MC, NA, NB, ME, NC, NCH. The "Short Gasoline CUEDC Cycle" SPC240 [6] was then developed, which is a simplified and universal version of the existing CUEDC. However, it is not suitable for testing diesel buses.

3.2. Results of fuel consumption assessment on real city routes when operating Ataman A092N6 buses for one year

Based on the year-round operation of Ataman A092N6 buses in the city for passenger transportation, fuel consumption information was collected from twelve buses. Table 1 shows the results of the study.

Table 1

Results of fuel consumption assessment on real city routes during operation of Ataman A092N6 buses for one year

Bus serial number	Mileage, km	Total fuel consumption, l	Calculated linear fuel consumption, l/100 km
1	91169.61	14983.89	16.4
2	81108.73	13795.78	17.0
3	79722.33	14131.89	17.7
4	43735.13	9096.42	19.0
5	91390.26	16089.84	20.8
6	44094.85	8364.89	17.6
7	47002.38	9967.58	21.2
8	48007.47	8938.19	18.6
9	53963.11	9582.00	17.8
10	44989.85	8230.97	18.3
11	50169.82	9356.06	18.6
12	53068.69	10448.25	19.7

Thus, the fuel consumption of buses during year-round operation is within the range of 16.4 to 21.2 l/100 km, which is within the limits of fuel consumption regulated by the manufacturer [1].

When testing the "Bogdan" A092 bus in the urban driving cycle proposed by JSC "Ukrbusprom", the fuel consumption was 18 l/100 km [5], which is also within the limits of the results of road tests.

3.3. Discussion of the results of assessing fuel consumption in standard driving cycles and in real bus operation

After analyzing the existing regulatory framework for determining linear fuel consumption by buses in the urban driving cycle, it was found that Ukraine currently lacks such a regulatory framework. GOST 20306-90 [2] became invalid at the beginning of 2022. The new draft DSTU, proposed by JSC "Ukrbusprom" in 2012, has not yet been implemented. There are also many countries (USA, EU countries, China, Japan, Australia) that have their own similar standards. Even in the USA and Germany, driving cycles have been developed for individual cities (Braunschweig, Aachen), which indicates the difference in the operation of buses in individual cities from the standard in force in a particular country. Therefore, there is no guarantee that one of the existing standards in force in countries around the world can be adequately implemented in Ukraine. In addition, Ukraine joined the Geneva Convention in 2000, which allowed the use of EU standards. However, some standards borrowed from EU countries had to be adapted to the realities of road transport operation in Ukraine.

Highway driving cycles (for example, shown in Fig. 1) are not at all suitable for assessing fuel consumption in the city, since urban traffic involves frequent stops and accelerations of the bus. The urban driving cycle in the USA takes into account the bus movement inherent in urban traffic (accelerations and stops), however, a feature of US cities is the large distances between stops, which is different from the cities of Ukraine.

Japanese and Chinese driving test cycles are not quite suitable for the realities of operation in Ukraine. This is explained by the fact that Japanese and Chinese cities are densely populated and urban traffic is much more saturated. Accordingly, it is characteristic that the movement is accompanied by frequent accelerations and decelerations.

Driving cycles in EU countries are used to check the environmental performance of buses, which is not entirely suitable for assessing fuel consumption, and there is also a need to develop additional (individual) test cycles for cities.

Real tests of twelve Ataman A092N6 buses in the city made it possible to obtain the average fuel consumption value for one year (Table 1).

It can be seen that the results range from 16.4 l/100 km to 21.2 l/100 km. Such results are explained by the operation of buses on different routes (different number of stops, number of passengers transported at the same time, condition of the road surface microprofile), and the individual driving style of a single driver. The representativeness error was calculated according to formula (1) and was $\Delta = 0.42$. Standard deviation $\sigma = 1.44$, calculated according to formula (2). Arithmetic mean $\bar{X} = 18.6$, calculated according to formula (3). The variance is determined by the formula (4) $D = 2.08$.

It should be noted that the results of fuel consumption, when tested on the basis of the proposed test cycle of JSC "Ukrbusprom", do not go beyond the results of the conducted studies of year-round operation of buses. Therefore, the test cycle [3] has the right to be implemented in real practice.

Unlike the considered cycles [6], the assessment in real year-round operation allows to determine the linear fuel consumption when operating in a specific city and on a specific route with the maximum approximation to the actual operation.

The use of the Mymemory memory unit (the so-called "black box") integrated into the vehicle system via the CAN bus makes it impossible to unauthorized disconnection and falsification of the results, therefore such results of the study will be the best in terms of reliability. Such studies have already been implemented in real practice and have confirmed the operability of such a method.

The limitation of this research is that for a full assessment of fuel consumption it is necessary to operate the bus on the same routes. Then, after a year of operation, determine the costs on each individual route, which will allow to estimate fuel consumption in even more specific operating conditions.

The disadvantages of this research are that a whole year of bus operation is required to collect statistical information. On the other hand, in a standard test cycle, fuel consumption can be determined in less than one day.

The development of this research is that such information recording units (Mymemory) are advisable to install on buses of other brands and, based on year-round operation, collect real statistical data in specific cities and permanent unchanging routes. This will allow either to fully confirm the proposed test cycles [3] or to develop recommendations for increasing their accuracy with further implementation.

The impact of martial law conditions. The results of the assessment of fuel consumption on real city routes during the operation of Ataman A092N6 buses for one year (Table 1) were not affected by martial law in any way. Since the accumulation of statistical data during year-round operation on twelve buses was recorded in the memory unit, which did not require any intervention. And after a year of operation, during scheduled maintenance at an authorized service station, the necessary information was downloaded. This approach allowed to obtain the necessary information with maximum convenience and minimal time consumption.

4. Conclusions

Based on the analysis of existing test urban driving cycles in the world, it was found that driving cycles mainly involve acceleration and deceleration at maximum fuel supply and during emergency braking, which can distort the realities of operation. Accordingly, there is no universal cycle that can fully describe the multivariate operation of buses in cities around the world. Therefore, the greatest reliability of the average linear fuel consumption will be provided by statistical data during the operation of the bus during the year in a specific city and on a specific route. The results of the year-round operation of the Ataman A092N6 buses allowed to obtain fuel consumption of 16.4–21.2 l/100 km, which does not exceed that declared by the manufacturer [1]. Also, the data obtained in the cycle developed by JSC "Ukrbusprom" (18 l/100 km) are within these limits, which confirms the operability of the proposed cycle. For further research, it is advisable to install information recording units on buses of other brands and collect real statistical data on the basis of year-round operation in specific cities and permanent unchanging routes. This will allow either to fully confirm the proposed test cycles [3] or to develop recommendations for increasing their accuracy with further implementation. In addition, with further research, it will be possible to implement this test cycle in Ukraine, which will significantly reduce the time for fuel consumption standardization and provide manufacturers with data on the approximate linear fuel consumption rate on city routes, as close as possible to real ones.

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Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship or other, that could influence the study and its results presented in this article.

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Data availability

The manuscript has no related data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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