DETERMINATION THE NORMS OF FUEL CONSUMPTION FOR BUSES IN THE PUBLIC TRANSPORTATION IN REAL CONDITIONS OF EXPLOITATION

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1. INTRODUCTION

Determination of norms of fuel consumption for different groups of buses that make up the fleet of one company for public transport, stems from the fact of their different tehnical characteristics and different service conditions on the routes where vehicles operate.

In this paper is present a case of determining norms of fuel consumption for a group of articulated buses ’’Solaris Urbino 18’’. The fleet GSP ’’Beograd’’ has 200 buses of this type that were acquired in the period August-December 2013. Of the planned number of 640 buses in operation on work days, this group accounts for about 31% of the vehicles in operation and represents the largest group of buses. At the time when norms determination, vehicles have passed the phase of elaboration of the vehices and their technical condition was optimal. Mileage of tested vehicles is ranged from of 60 000 and 90 000 km.

When were buses purchased an integral part of the documentation of the tender was the test fuel consumption according to the method SORT 1 (urban cycle). The manufacturer has declared consumption for this test of 56 L / 100km. The question is how this result is close to the actual fuel consumption in the real system. In Figure 1 is presented one of the buses from that group with the basic technical characteristics

SOLARIS Urbino 18
Engine: DAF PR 228 Euro 5
Power: 231 KW
Torque 1275 Nm
Volume: 9,186 cm^3
Transmission: ZF-6AP
Length: 18.000 mm
Width: 2,550 mm
Height: 3,050 mm
Vehicle capacity: 159 passengeres
Year: 2013
Number of vehicles in fleet: 200

Figure 1 Articulated bus Solaris Urbino 18 with basic technical data

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2. THE INFLUENTIAL FACTORS ON THE FUEL CONSUMPTION OF BUSES FOR URBAN TRANSPORT

The fuel consumption of buses is a complex function of several independent factors. The most important factors to fuel consumption are:

- Performance vehicles (powertrain features-power, torque, specific consumption, transmission characteristics, weight, aerodynamics)
- Characteristics of road (longitudinal gradients, horizontal curve, adhesion characteristics of road)
- Traffic conditions (traffic flow, number of passengers in bus , keeping at the traffic lights, the number of stations, etc.)
- Period of exploitation (winter, summer - the use of air conditioners)
- Technique vehicle handling.

Fuel consumption of buses for public transport in terms of the characteristics in direct connection with the constructive and exploitation characteristics of the engine, the load of the bus, the size of the resistance movement, the characteristics of transmission of the remaining components.

The density and structure of traffic flow, the level of regulation of intersections and the number of stations on the route of the most important factors when the conditions of the bus in question. These impacts can best demonstrate the value of exploitation speed (Ve) by bus realized on the line [1].

$$Ve = 2Lr \cdot Te\text{-}1 \qquad [km \cdot h^{-1}] \qquad (1)$$

$$Ve = 2L_r \cdot (Tv + Tss + Tts)^{-1} \qquad [km \cdot h^{-1}] \qquad (2)$$

Ve- exploitation speed $[km \bullet h^{-1}]$

Lr - length of route [km]

Te - the duration of use [h]

Tv - driving time [h]

Tss- time spent waiting at stations [h]

Tts - time spent at a traffic standstill [h].

If we take into account the time a vehicle spends in the terminal while waiting for the departure (Tt - time spent at the terminus), then we have a turnaround time (To = Tv + Tss + Tts + Tt) gives a speed turnaround such as:

$$Vo = 2L_r \cdot To^{-1} \quad [km \cdot h^{-1}] \qquad (3)$$

$$Ve>Vo \qquad (4)$$

From the expressions on the operating speed, we can conclude that as conditions for the movement tends to a greater number of stations, signal intersections, the frequent delays in traffic flow to the lower speed. With the decline of the value of exploitation speed increases fuel consumption which can be show the following picture:

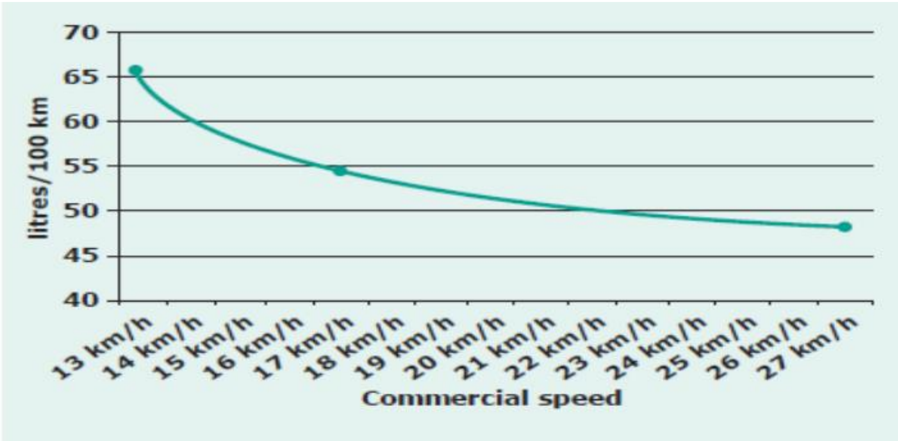

Figure 2 Dependence of fuel consumption and exploitation speed for articulated bus [2]

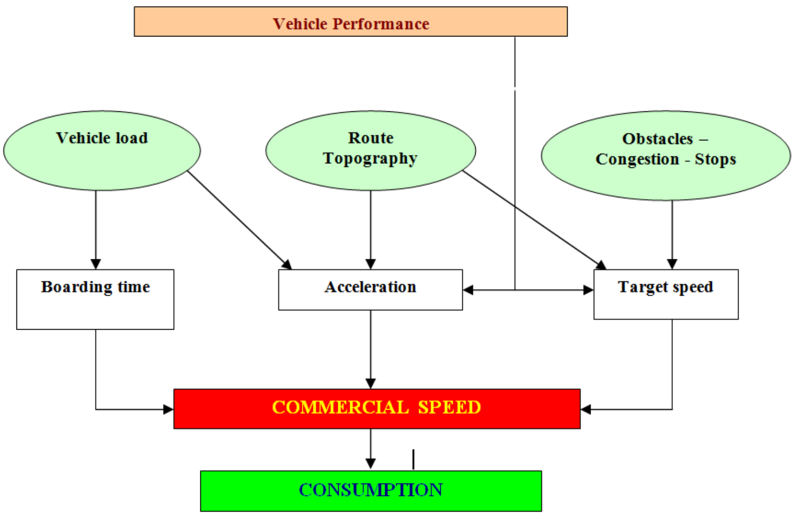

Figure 3 Influential factors on fuel consumption

From Figure 3 [2] it can be concluded that the exploitation speed of movement of buses for public transport in direct dependence on the influencing factors while fuel consumption in inverse proportion with the exploitation speed as already presented in Figure 2. For this reason, the greatest number of empirical models of fuel consumption (Akcelik-Richardson model, CNR-model, Gattuso model) as a base the size of the benefit precisely the exploitation speed of the bus [3].

3. METHODOLOGY OF DETERMINING FUEL CONSUMPTION FOR BUSES SOLARIS URBINO 18

Determining norms of consumption of fuel for vehicle group "Solaris Urbino 18", are done on the basis of the results obtained :

- The statistical method based on the measurement of fuel consumption in real conditions of exploitation by buses and lines [4]
- The research covered the period from 1.3-15.4.2014 and 1.10-31.10.2014.year, given that months: March, April and October are the authoritative period of analysis from the aspect of intensity of passenger flows, traffic conditions and external temperature as the most influential factors affecting fuel consumption in general
- The results obtained on the fuel consumption at the level of the working day, on selected lines for each bus separately. Everyday was measured quantity of fuel through the electronic system to refuel, for each bus separately. Daily mileage is obtained on the basis of reading from tachograph
- Results of the daily consumption of fuel that had extremely high values as a result of disruptions in traffic or discrepancies in the records of refueling were not taken into analysis.

It is known that the fuel consumption of motor vehicles as a stochastic phenomenon is subject to the law of normal (Gaussian) distribution. This law allows the use of statistical methods, it possible for every type of vehicles are given estimate the expected fuel consumption.

Based on a representative sample (Xi, i = 1, n) performed a statistical analysis of the results of the fuel consumption of buses Solaris Urbino 18 on lines using the mean value (Xs) and standard deviation (s).

$$X_s = \frac{X_1 + X_2 + X_3 \dots + X_n}{n} \tag{5}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_s)^2}{n}} \tag{6}$$

The norm of fuel consumption was obtained on the basis of interval estimates of the mean fuel consumption (μ) of the basic set with a probability of 95%, using a normal distribution for the sample n≥ 30th [5].

$$P\left(X_s - 1.96\frac{s}{\sqrt{n}} < \mu < X_s + 1.96\frac{s}{\sqrt{n}}\right) = 0.95 \tag{7}$$

4. EXAMPLE OF MEASURING AND NORMS FUEL CONSUMPTION ON THE LINE NO.17

Line No.17 (Konjarnik-Zemun), according to the spatial position is the tangential line, of medium length (Lr) of 16.1 km. (Figure 5). Average exploitation speed (Ve) is 18.5 km h-1. The number of stations in the direction " A " is 27, in the direction of "B" is 30.

Average distance between stations is 575 meters. Line in terms of the number of passengers is one of the highly loaded lines [7].

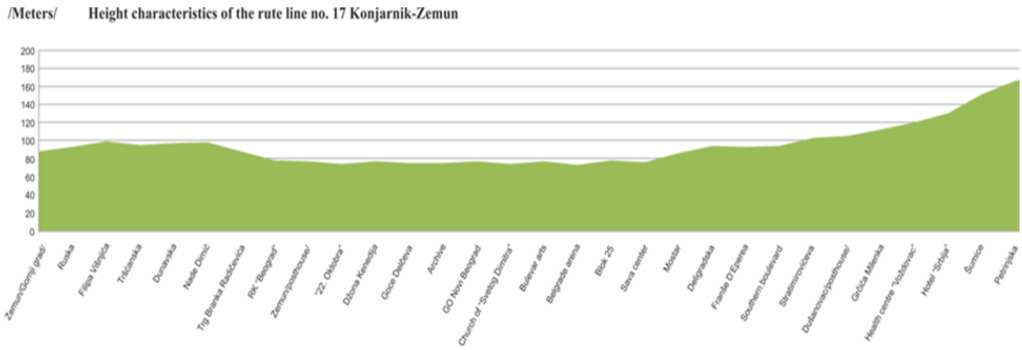

Figure 4 High characteristics of the rute line no. 17 Konjarnik-Zemun

Figure 5 Spatial position and altitude characteristics of the route line No.17

In table 1. presents the results of measurement of fuel consumption on city line No.17 (Konjarnik-Zemun) for 5 buses SOLARIS Urbino18 (Garage Number: 3002,3003,3016,3017,3018) during October 2014 [4].

Table 1 Results of measurement of fuel consumption on the line 17 (October 2014)

Number of measure ment	Consum ption [L/100 km]	Number of measure ment	Consum ption [L/100 km]	Number of measure ment	Consum ption [L/100 km]	Number of measure ment	Consum ption [L/100 km]
1	**44.03**	21	**52.33**	41	**53.6**	61	**54.92**
2	**46.31**	22	**52.36**	42	**53.63**	62	**55.02**
3	**47.57**	23	**52.46**	43	**53.63**	63	**55.07**
4	**48.56**	24	**52.54**	44	**53.69**	64	**55.2**
5	**48.98**	25	**52.54**	45	**53.69**	65	**55.2**
6	**49.18**	26	**52.6**	46	**53.82**	66	**55.25**
7	**49.23**	27	**52.65**	47	**53.82**	67	**55.33**
8	**49.24**	28	**52.67**	48	**53.85**	68	**55.42**
9	**49.38**	29	**52.8**	49	**53.9**	69	**55.76**
10	**49.74**	30	**52.83**	50	**54.05**	70	**55.88**
11	**50.00**	31	**52.88**	51	**54.24**	71	**56.45**
12	**50.41**	32	**52.88**	52	**54.43**	72	**56.5**
13	**50.71**	33	**52.91**	53	**54.44**	73	**58.31**
14	**51.08**	34	**52.94**	54	**54.51**	74	**58.47**
15	**51.44**	35	**53.04**	55	**54.51**	75	**60.48**
16	**51.53**	36	**53.05**	56	**54.57**	76	**60.82**
17	**51.6**	37	**53.28**	57	**54.58**	77	**61.45**
18	**51.86**	38	**53.28**	58	**54.62**	78	**62.25**
19	**51.87**	39	**53.28**	59	**54.64**		
20	**52.22**	40	**53.36**	60	**54.92**		

Processing of a statistical sample of 78 measurements, obtained the arithmetic average (Xs) 53.36 L / 100 km and standard deviation (s) 3.06 L/100 km.

To verify that the distribution of the test sample is consistent with "Normal"(Gauss) distribution, we will distribute samples of fuel consumption in the class, as presented at the figure 5.

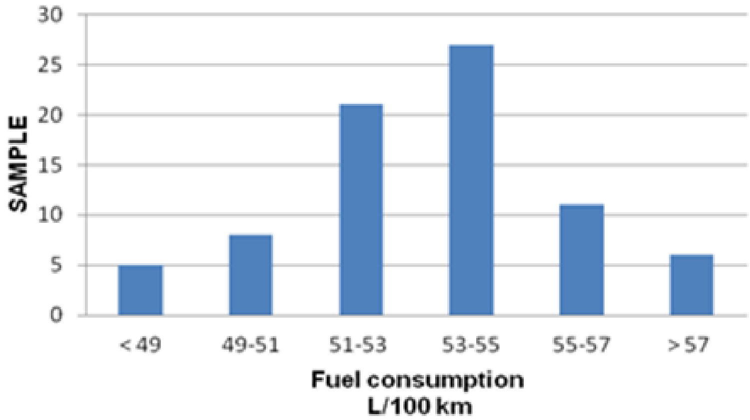

Figure 6 Distribution of fuel consumption samples in the class for Solaris Urbino 18 buses on the line No.17

Using a statistical test "χ^2" (Chi-square test) of the verify accordance the theoretical with empirical distribution of the sample (Figure 7).

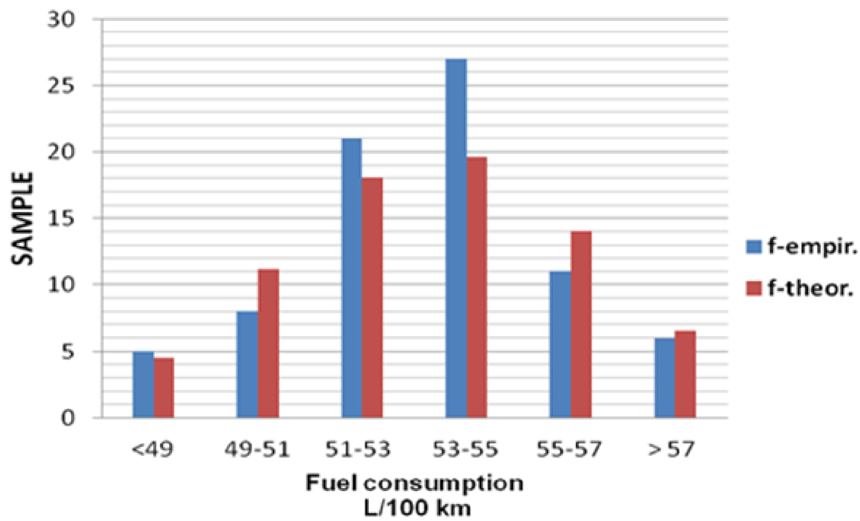

Figure 7 Empirical and theoretical χ^2 distribution sample of fuel consumption on the line No.17

$$\chi^2_{0,05} = 4.929 \quad (8)$$

respectively $\chi^2_{0,05} = 4.929 < 7.815$ (9)

where 7,815 table value $\chi^2_{0,05}$, k = r-m-1 = 3 degrees of freedom (r = number of classes 6, m = 2 number degrees of freedom for ''normal'' distribution). Given that the resulting value $\chi^2_{0,05}$ less than the value of the table , has demonstrated compliance with the ''normal'' distribution.

Based on the results of measuring the arithmetic value (Xs), standard deviation (s), normative consumption was obtained on the basis of interval estimates of the mean basic set with a probability of 95%, using a normal distribution for the sample n≥ 30 [5].

$$P\left(X_s - 1.96\frac{s}{\sqrt{n}} < \mu < X_s + 1.96\frac{s}{\sqrt{n}}\right) = 0.95 \qquad (10)$$

In the present case of P (52.69 <μ <54.05) = 0.95, with a probability of 0,95, we can argue that on the city's line N0.17 for buses Solaris Urbino 18, the average consumption of fuel in the range of 52.69 to 54.05 L/100 km, which is the norm of consumption using the above methodology can be reached the relevant norms of consumption of fuel for other lines where buses SOLARIS Urbino18 are worked. The following figures are examples of the empirical distribution of fuel consumption on the lines No.23;75;83.

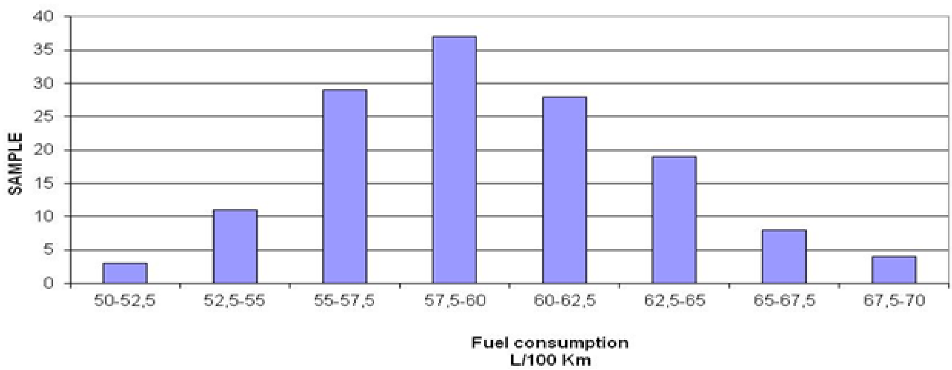

Figure 8 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.23

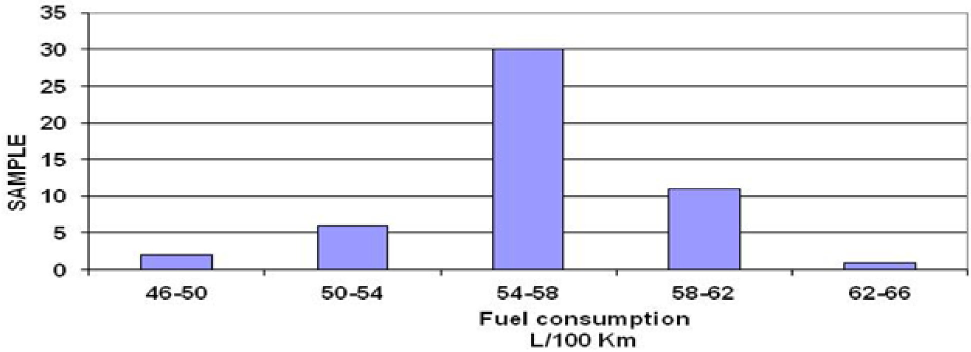

Figure 9 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.75

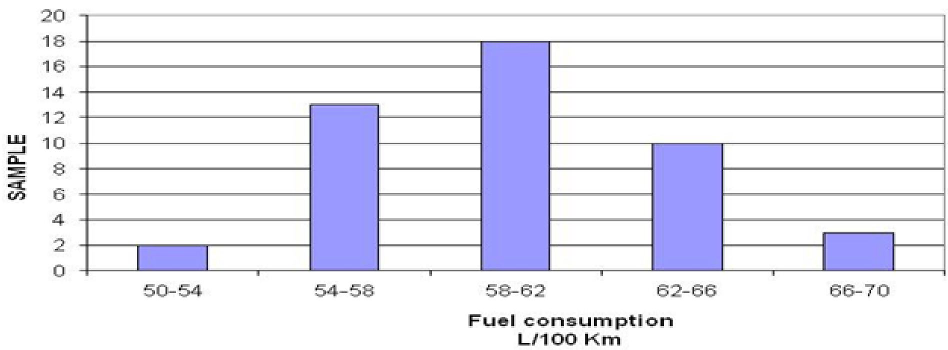

Figure 10 The empirical distribution of fuel consumption for Solaris Urbino 18, on the line no.83

In Table No. 2 presents norms of fuel consumption for buses SOLARIS Urbino 18, on city lines, are included in the research (October 2014).

Table 2 Norms of fuel consumption for buses SOLARIS Urbino 18

No.line	Exploitation speed [Km h^{-1}]	Average consumption [X_s] [L/100 km]	Stan.deviation [s] [L/100 km]	Sample size	Norms of fuel consumption [L/100 Km] ''from ''	''to''
16	15.6	59.18	4.09	88	58.33	60.04
17	18.5	53.36	3.06	78	52.69	54.05
18	20.4	54.37	3.76	81	53.55	55.19
23	17.1	59.57	4.07	140	58.90	60.25
27	15.1	59.94	1.93	57	59.44	60.45
27E	16.3	58.80	2.82	51	58.06	59.61
31	13.8	62.43	4.78	84	61.41	63.46
37	16.3	56.01	2.72	76	55.40	56.62
43	16.7	51.30	2.81	72	50.02	52.57
51	15.8	52.86	1.99	77	52.41	53.30
52	16.8	56.34	2.99	46	55.47	57.20
53	18.1	56.32	2.57	31	55.42	57.23
56	19.6	52.88	2.55	32	51.99	53.77
58	17.3	51.98	3.39	35	50.86	53.10
59	18.4	60.71	2.63	52	59.99	61.43
65	16.1	56.31	3.19	63	55.53	57.10
68	17.8	54.66	3.29	42	53.67	55.66
71	16.3	53.21	1.75	43	52.68	53.73
72	23	51.75	3.20	42	50.79	52.72
75	17.3	56.37	3.01	50	55.54	57.21
77	14.9	55.52	2.94	67	54.81	56.22
83	15	60.50	3.60	46	59.46	61.54
85	18.2	52.48	1.57	30	51.92	53.05
88	20.6	52.00	3.05	44	51.10	52.90
89	17.8	53.23	3.65	51	52.23	54.24
95	19.4	53.29	3.72	102	52.57	54.02
96	19.1	51.79	3.17	31	50.68	52.91
101	28.1	44.63	3.40	38	43.55	45.79
531	26.7	39.16	1.65	34	38.60	39.71

Based on the study, results are presented in the table no.2, we can give a correlative relationship between the average fuel consumption and exploitation speed (Figure 11) for some characteristic lines: urban-diametrical (No:31;83;16), urban-radial (No:52;75); urban-tangential (No:17;88) and one suburban line (No.101).

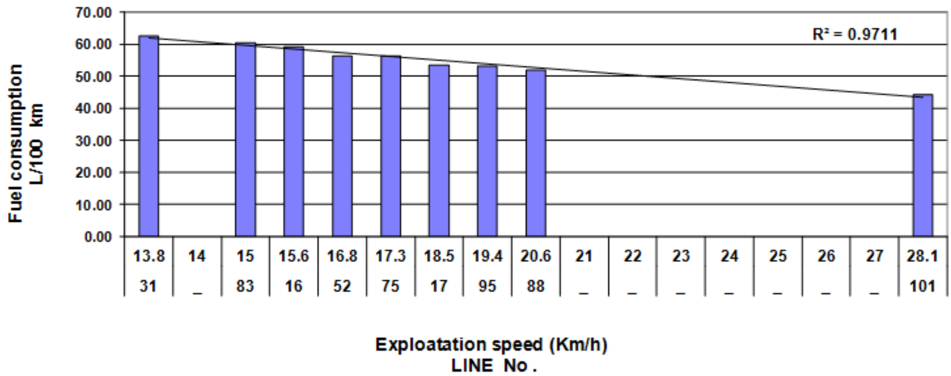

Figure 11 Correlation dependence of fuel consumption and exploitation speed for SOLARIS Urbino 18

Since that the correlation coefficient R^2 = 0.971, extremely high, it indicates an extremely strong the linear relationship between fuel consumption and exploitation speed. If in linear regression equation, change the value of exploitation speeds of 12-30 km h^{-1}, which is a realistic range of exploitation speeds and to cover all operating modes: City, combined, suburban, we can reach results norms of consumption as shown in Table 3.

Table 3 Norms of fuel consumption for a group of vehicles SOLARIS Urbino18, obtained from the regression

Exploitation speed [Km h^{-1}]	Expected consumption [L/100km]	Norms of fuel consumption [L/100km] 'from''	'to''
12	63.4	62.14	64.66
13	61.58	60.32	62.84
14	60.46	59.2	61.72
15	59.35	58.09	60.61
16	58.23	56.97	59.49
17	57.11	55.85	58.37
18	55.99	54.73	57.25
19	54.87	53.61	56.13
20	53.76	52.5	55.02
21	52.64	51.38	53.9
22	51.52	50.26	52.78

23	50.4	49.14	51.66
24	49.28	48.02	50.54
25	48.17	46.91	49.43
26	47.05	45.79	48.31
27	45.93	44.67	47.19
28	44.81	43.55	46.07
29	43.69	42.43	44.95
30	42.58	41.32	43.84

If we look at fuel consumption individually for each vehicle SOLARIS Urbino 18, which is the generated in October 2014 in the regular operation in depot " Novi Beograd ", we can conclude the following:

- The average fuel consumption for a group of buses SOLARIS Urbino 18 (a total of 100 buses) is 54.05 L/100 km
- All vehicles operate exclusively on urban or urban-suburban lines and depending on the exploitation of speed and load, the consumption ranges from 49.4 to 62.3 L/100 km
- The results obtained fuel consumption in real terms in October 2014 and norms of consumption that are made on the basis of the sample have a high degree of concurrency
- If the compare values of fuel consumption on the line no.17 which was obtained by statistical method 53.36 L/100 km, with the results obtained in the test using the method ’’SORT 1’’, where the resultant consumption of 56 L/100 km [6], we conclude that it is expected , considering that this is a more difficult driving cycle that has the operating speed of 12.7 km h^{-1}, compared to the exploitation speed on the line No.17 which is 18.5 km h^{-1}
- Fuel consumption during the period when using air conditioning on the bus to be increased by 15% compared.

5. CONCLUSIONS

Determination of norms of fuel consumption for buses operating in the public transportation system is an important indicator of exploitation, which should serve as a benchmark when analysing fuel economy bus. The necessity of defining norms of fuel consumption for each type of city bus, depending on the line where he works in real conditions of exploitation gives all the specifics of the given line. Monitoring of fuel consumption of each bus allows analysis and comparison with the defined standards of consumption. Savko deviation from norms means taking appropriate technical-organizational measures to return consumption within prescribed limits.

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