MEASUREMENT THE FUEL CONSUMPTION OF BUSES FOR PUBLIC TRANSPORT BY THE METHODOLOGY ''SORT'' (STANDARDISED ON-ROAD TESTS CYCLES)

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INTRODUCTION

The fuel consumption is presenting an important aspect of operation the buses for public transportation specifically in terms of optimizing the total cost of the life cycle. Also in the last time it is one of the mandatory criteria in tenders for the purchase of new buses. Until 2009, was not standardized methodology that is related to this issue, so the manufacturers of buses declared consumption that were based on individual factory tests.

Also many bus manufacturers declared that the factory consumption based on testing performed on engine test stands. However, nor the ESC cycle (European Steady Cycle) prescribing 13 fixed points of measuring nor the ETC cycle (European Transient Cycle), with more dynamic characteristics, take into account the whole vehicle. Furthermore these engines test cycles in no way adequately reflect the stop-and-go operation of a scheduled service bus.

For these reasons, classic normative tests are not sufficient to simulate the operation of a public transport vehicle. Therefore it seemed indispensable to design on-road test cycles for the whole vehicle in the framework of the SORT project, based on statistically generated data from several European transport companies (commercial speed, average time spent at stops, average distance between them, the load, etc.).

The goal of SORT methodology is standardized cycle test for bus, which will measure the fuel consumption and be applied to all bus manufacturers and operators in the public transportation system.

INFLUENTIAL FACTORS ON FUEL CONSUMPTION OF BUSES FOR PUBLIC TRANSPORT

In order to define the most important influencing factors(Figure 1), it is necessary to take into account a number of typical parameters such as traffic density, numbers of stops (either for the boarding and alighting of passengers or simply required by the environment), route topography, vehicle loads, and commercial speed. Although integrating so many variables is a difficult process, these parameters can all be seen to have a direct influence on commercial speed, which therefore becomes a kind of common denominator for the different variables [1].

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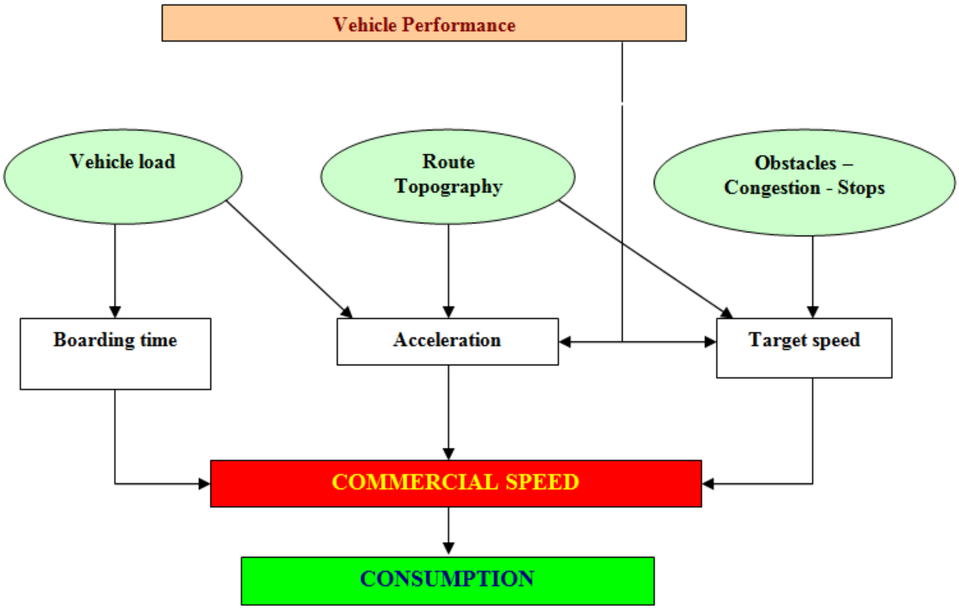


Figure1 Influential factors on fuel consumption

Commercial speed can be seen as the key parameter differentiating distinct operation patterns. Indeed, the graph above shows that any change of route severity impacts on commercial speed and thus on consumption (which is inversely proportional). Consumption reduction following increased commercial speed (Figure 2) is a paradox well-known to operators: commercial speed can only be influenced by structural measures such as dedicated bus lanes, and consequently a reduction of congestion-related stops, which has a favourable impact on consumption [2].

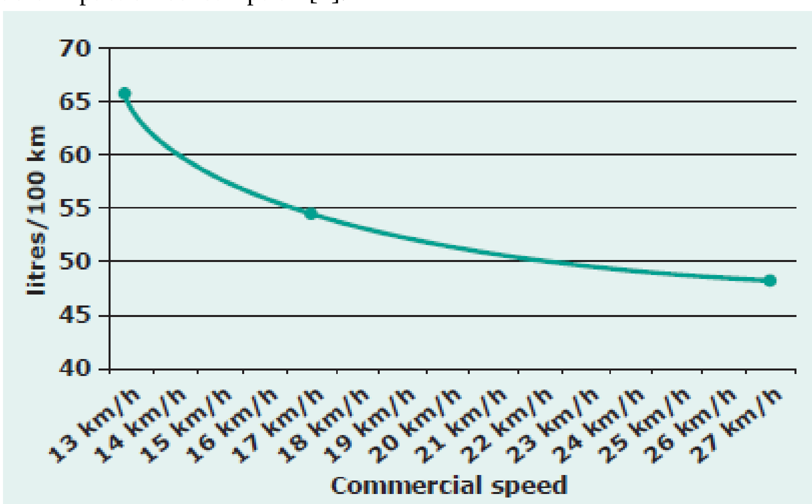


Figure 2 The consumption of an articulated bus according to its commercial speed

CYCLE DESIGN

Each company would like to have a cycle that reflects its operation pattern. This is clearly not feasible. As many cycles as bus routes would be needed. Moreover, in some cities, the same vehicles run on different routes, with their own features. Out of this situation, the basic SORT philosophy was born: designing a given number of cycles in such a way that companies can assess their operation as a combination of several base cycles. The basic cycle (Figure 3): SORT 1 (urban cycle), SORT 2 (combined urban-suburban) and SORT 3 (suburban cycle).

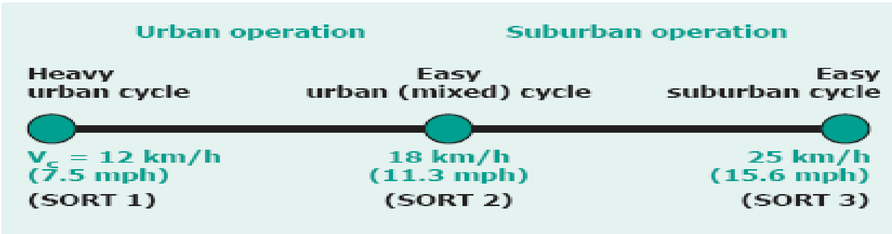
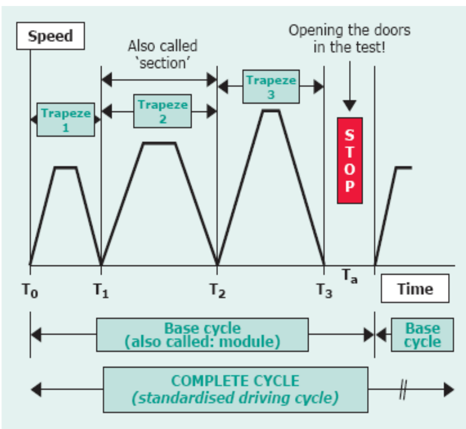


Figure 3 SORT base cycles

A proposed cycle is thus made up of the repetition of the identical base cycle featured by an average speed and a length, and driven with a simulated load . The need for result confidence could require increasing the number of repetitions in a complete cycle until the overall results lie within a given standard deviation. The sequence of trapezes (sections) in one module is intended to reflect the driving conditions of a public transport vehicle: frequent stops (either with opening of doors for boarding/alighting, or stops due to traffic conditions (traffic lights, congestion) [3]. Total idle time within a trapeze will be defined, as well as total duration of the base cycle module, in order to reach a pre-established mean speed, which will be dealt with later. These stops punctuate the trapezes, each of which defined is by an acceleration, a constant speed stretch (section target speed) and a braking phase (Figure 4).



	SORT 1	SORT 2	SORT 3
Rated average speed (km/h)	12.1	18	25.3
Stops/km	5.8	3.3	2.1
Stop time (%)	39.7	33.4	20.1
Trapeze 1 v-const. (km/h)/ length (m)	20/100	20/100	30/200
Acceleration (m/s²)	1.03	1.03	0.77
Trapeze 2 v-const. (km/h)/ length (m)	30/200	40/220	50/600
Acceleration (m/s²)	0.77	0.62	0.57
Trapeze 3 v-const. (km/h)/ length (m)	40/220	50/600	60/650
Acceleration (m/s²)	0.62	0.57	0.46
Length of stops (s)	20/20/20	20/20/20	20/10/10
Total length (m)	520	920	1,450
Deceleration (m/s²)	0.8	0.8	0.8

Figure 4 Structure of the bases cycles

For example SORT 1, city cycle consists of three trapezoids with a constant target speed of 20 km/h, 30km/h, 40 km/h. After each trapezoid provided a retention time of

20seconds, so this cycle is characterized by the total time idling than 60 seconds. The average speed of exploitation of this test is about 12 km/h. Length of the test track is 520 m (Figure 5). For each variety, the cycle is defined by a lump load of 3,200 kg for the solo bus, and 4,978 kg for the articulated bus [1].

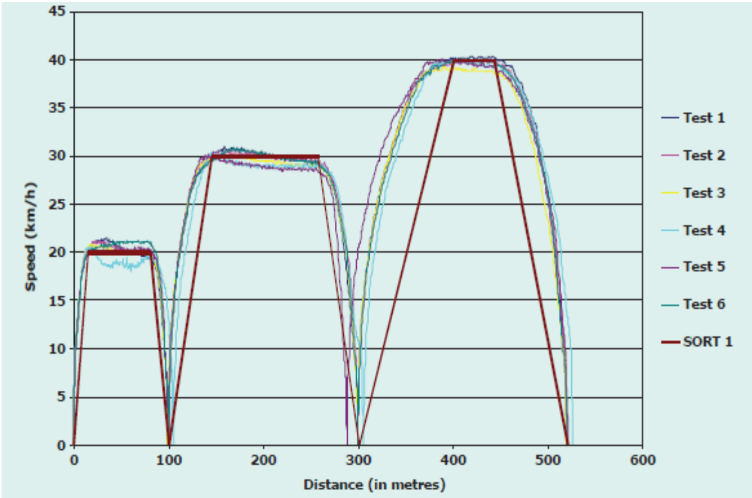


Figure 5 A good example of the conducted test SORT 1

MEASURING METHOD

Measuring instruments

In order to achieve comparable and reproducible measuring results, the instruments must fulfil the minimum requirements listed below (Table 1):

Table 1 Measuring instruments-minimum requirements

Meas. Instrument	Accuracy
Fuel-flow meter or a Gravimetric fuel meter	+ / - 2%
Speed	+ / - 0.5%
Distance measuring device (for positioning of traffic cones)	+ / - 0.2%

The measuring instruments calibration and maintenance must comply with the requirements as under DIN EN ISO 9000.

MEASURED VARIABLES

Speed

Vehicle speed is recorded during the measuring run. Here, the recording serves to monitor adherence to the trapezoidal speed. The correctness of the measurement must be checked during the breaks between two measurements. In the event of any deviations the measurement is to be repeated.

Time

The time required for the SORT cycles (including each stop period) is documented. The time and the resulting average speed are entered into the report.

Fuel consumption

The fuel consumption of the individual measuring runs is documented. For volumetric measurement of the fuel consumption, the measured values have to be corrected for a temperature of 20 °C.

Fuel temperature

The fuel temperature is measured (for volumetric measurement) at the start and end of each cycle in the area of the measuring chamber. The mean value is used for converting the fuel consumption to standard conditions

Fuel density

The density of the fuel used is measured at a temperature of 20 °C and entered into the report.

MEASURING PROCESS

The following procedure is recommended for the measuring process: [1]

- Measure out route points (1, 2, 3, 4) for the individual SORT cycles and mark them using traffic cones
  - The SORT 1 cycle, which is only 520 m, must be run through at least twice in succession (= 1040 m)
  - The SORT 2 (920 m) and SORT 3 (1450 m) cycles need to be run through, at least once
  - Should the cycle be run through more than once, without pause between two runs, the results of the overall distance shall be taken into account.
- The consumption measurements for each respective cycle are to be repeated until 3 measurements lie within an accuracy requirement of 2%. To calculate the accuracy, the difference between the maximum and minimum consumption value of the three measurements is divided by the minimum value ((Cmax-Cmin)/Cmin x 100). (Figure 6)
- The tolerance for the trapezoidal target speed is ± 1 km/h. During the transition from acceleration to steady-state driving, a maximum deviation of +3 km/h is permitted for a brief period.
- No more than 10 minutes should elapse between each measurement

SORT 1 / Direction North						
Measured values (X)		Values ordered by increasing order		Numbers of the considered values	Gap	Mean value
1	49.3	1	49.3	1, 7, 11	3.5	
3	52.0	7	50.6	7, 11, 9	2.3	
5	53.0	11	51.1	**11, 9, 3**	**1.7**	**51.63**
7	50.6	9	51.8	9, 3, 5	2.3	
9	51.8	3	52.0			
11	51.1	5	53.0			

SORT 1 / Direction South						
Measured values (X)		Values ordered by increasing order		Numbers of the considered values	Gap	Mean value
2	51.8	6	50.3	6, 12, 4	1.9	50.70
4	51.3	12	50.5	12, 4, 2	2.5	
6	50.3	4	51.3	4, 2, 8	1.5	
8	52.1	2	51.8	2, 8, 10	0.8	
10	52.2	8	52.1			
12	50.5	10	52.2			

Value SORT 1 = (51.63 + 50.70) / 2 = 51.17 litres

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5	53.0	11	51.1	**11, 9, 3**	**1.7**	**51.63**
7	50.6	9	51.8	9, 3, 5	2.3	
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8	52.1	2	51.8	2, 8, 10	0.8	
10	52.2	8	52.1			
12	50.5	10	52.2			

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Figure 6 An example of a calculation of the consumption SORT 1[4]

PRACTICAL EXPERIENCE ON THE CONDUCTED TEST SORT 1

In October of 2012. "Bus manufacturer Solaris Bus & Coach SA" won on the tender for the purchase 200 articulated buses, which was announced by the City of Belgrade. One of the criteria for selecting was fuel consumption. Articulated bus Solaris Urbino 18, was declared an average fuel consumption of 56 l/100 km in city mode of exploitation according to the methodology SORT 1. According to the obligation of contracts "Solaris Bus & Coach SA" after delivery, was obliged to carry out a control test fuel according to the methodology SORT 1 and prove that the declared fuel consumption , which was on the tender prevail. Delivery of 200 articulated buses were conducted in the period August-November 2013, within five contingents. For each contingent was determined a bus, on which will be measured the fuel consumption by the methodology SORT 1. The difference in fuel consumption on the control test, in relation to the declared value of the tender can be up to 5 % . In the case of consumption more than 5 % of declared " Solaris Bus & Coach SA" is required to pay penalties amounting to 2 % of the value of the each contingent [6].

Buses "Solaris Urbino 18", which have been tested: Vehicle No. 3002 , registration number: BG 728 –GC; Vehicle No. 3030, registration number: BG 753- WJ; Vehicle No. 3099, registration number: BG - 762 PZ; Vehicle No. 3110, registration number: BG 737 – HS; Vehicle number 3166, registration number: BG - 753 YC.

Tehnical data:

Length	18.000 mm
Width	2.550 mm
Height	3.050 mm
No. of passengers	159
No. of seats	40
Engine	DAF PR 228 (Euro 5)
Volume (cm3)	9.186
Power (KW) min-1	231/1900
Max torque (Nm) min-1	1275 /710-1.100
Gear	ZF-6AP
Front axle	ZF RL 75 EC
Drive axle	ZF AV 132
Centre axle	ZF AVN 132
Fuel tank	350 L
Ad blue tank	40 L

Figure 7Solaris Urbino 18, articulated city bus

Testing according methodology SORT 1 (urban cycle), was performed by accredited certification company

"APPLUS+IDIADA" Barcelona on specially prepared polygon "Santa Oliva" in the period from February to April of 2014. Test ground on which testing was done, has specially prepared, length of track 2x520 meters, which simulates the exploitation of buses in typical urban conditions, which means little exploitation speed (12-13 km/h) , frequent acceleration to 20, 30, 40 km/h, deceleration, braking, time on stop.

Before the test, vehicle was loaded with sacks of sand and 3 vessel with water to a simulated load of 50 % of the number of passengers in the vehicle.

Table 2 Results of measurements of fuel consumption, according methodology SORT 1, on the polygon'' Santa Oliva'' [7]

Garage number	Consumption on the test (L/100Km)	Declared consum. on the tender (L/100Km)	Difference (L/100Km)	%	Period	Mileage before test (Km)	Wind speed (m/s)	Temperature (C)
3002	57,2	56	1,2	2,14	18.02.2014	56193	0,6-1,0	12,1
3030	56,5	56	0,5	0,89	05.03.2014	46456	0,4-1,9	10,5
3110	55,30	56	-0,7	1,25	11.03.2014	42287	0,2-1,4	11,4
3099	58,2	56	2,2	3,93	31.03.2014	34819	1,4-1,5	13,1
3166	58,7	56	2,7	4,82	02.04.2014	32004	1,2-3,0	17,1

Based on the results of measurements of fuel consumption per Methodology SORT 1 (Table 1), it can be concluded that for every vehicle that was the subject of testing, were within the permissible limits of up to 5% compared to the stated consumption, which was at the tender (56 L/100 km). The average fuel consumption measured for all five vehicles that were tested by the methodology SORT1 is 57.18 l/100 km, which is 2.11% higher than the consumption on the tender.

The following table 3, presents a comparative view of the results of fuel consumption with a polygon test, results and consumption in real operating conditions, where vehicles operate for a period 1.3-15.4.2014.

Table 3 Comparison of fuel consumption on the test and real conditions of exploitation[5]

Garage number	Consumption on the test (L/100Km)	Consumption in real exploitation (L/100Km)	Difference (L/100Km)	%	Line
3002	57,2	52,12	-5,08	-8,88	17
3030	56,5	52,11	-4,39	-7,77	88
3110	55,30	57,66	2,36	4,27	23
3099	58,2	51,86	-6,34	-10,89	88
3166	58,7	55,85	-2,85	-4,86	65

Table 4 Average fuel consumption for the Solaris Urbino 18 (all vehicles) per month [5]

Month	Average fuel consumption, (L/100 Km)
September 2013	59,39
October 2013	56,51
November 2013	54,45
December 2013	54,62
January 2014	55,41
February 2014	54,62
March 2014	54,45
April 2014	53,88
May 2014	55,75
Average	55,45

From table 4, conclude that the average fuel consumption for a group of vehicles Solaris Urbino 18 in the period September 2013 to May of 2014. amount of 55.45 l/100 km.

CONCLUSIONS

Presented SORT methodology is an important tool in the preparation of tenders for the purchase of new buses and the choice of optimal drive configuration in terms of fuel economy. Results of the test of fuel consumption by SORT 1 (57.18 l/100 km), declared of consumption on the tender (56 L/100 km) and the consumption in the real operations (55.45 l/100 km) are very close value with small deviations .

The selected configuration of the engine and transmission on vehicles Solaris Urbino 18, fully meets the high weight factors of using the buses in Belgrade and demand for economic fuel consumption.

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