ASSESSMENT OF THE ECONOMY OF MUNICIPAL BUS OPERATION

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Abstract. The aim of the research was focused to evaluate operational economy of two identical buses with using two different fuels. Research concerning economy of bus operation was ordered on request by the transport company that operates the buses. The transport company that operates the buses requested the survey to verify the operational economy of bus vehicles with the engine on combustion of CNG. Only the costs associated with fuel consumption were counted. The cost at acquisition of the vehicle and the cost of service inspections were not counted into this project. The measurements were conducted in the city of Nitra and the bus route constituted the route where the buses are operated. The buses were alternated at regular intervals on the same bus route. Driver A drove on the bus SOR BN 12 Ekobus City Plus (Bus 1) with the engine CUMMINS WESTPORT Plus. This type of combustion engine was rebuilt on combustion of compressed natural gas (CNG). Driver B drove on the bus SOR BN 12 (Bus 2) with classic diesel engine. Technical parameters of both engines are identical. The only difference is in the type of fuel. The base for data processing consisted of the work evidence of the drivers in the form of recording sheets determining the actual fuel consumption. The paper comprises assessment of fuel consumption by both drivers as recorded in the bus log books and finally at comparing the fuel consumption in particular months. Since the survey was conducted during the period November 2014 to October 2015, 12 record sheets were completed.

Keywords: alternative fuel, data collection, fuel consumption, measuring.

Introduction

The driver is affecting the fuel consumption by his driving technique and overall care of the vehicle, which is an integral part of the driver at work. Correct driving technique requires not only practical experience, but also knowledge of the design of the selected type of the motor vehicle. The technique of driving at diesel engines may negatively affect fuel consumption by 20-25 % [1]. The actual influence degree of driving techniques on fuel economy is directly related to the operating conditions and circumstances. The effort to reduce the fuel consumption of road vehicles must be always based on a specific knowledge of all factors that affect the fuel consumption. This applies chiefly for companies, which operate cars, trucks or buses, because the fuel economy of vehicles is an important factor in overall economic performance for them [2]. Ensuring of economical operation of cars does not affect only their fuel consumption, but also other important factors, such as the amount of exhaust gas emissions, reliability, technical readiness of the car etc. Several factors affect the fuel consumption directly and we can evaluate their impact, such as the technical parameters of the vehicle type and design, while others affect indirectly and we cannot precisely define the extent of their influence. Individual factors affecting fuel consumption are influencing each other, meaning that they have reciprocal links. The whole issue of fuel consumption should be understood systematically together with the solution approach [3]. The poor driving technique of the driver characterized by a hard and penetrative way of driving will be reflected within a short time on the technical condition of the car. Conversely, the best driver cannot drive economically with the vehicle in poor technical condition. The attainable speed and smoothness of driving are affected by the route properties and traffic flow characteristics, which affect the fuel consumption as well. Particularly the quality of traffic management can generate significant savings in urban traffic. It is important to remove various barriers, which obstruct the fluency of the traffic. Interaction between the impact of the transport route and driving technique of the driver is very important in terms of economy. The optimal driving conditions can be achieved by construction of quality communications, which positively affect the overall fuel economy of vehicles [4].

Materials and methods

The examination of the impact of the driver on operational economy of the vehicle was focused on the average fuel consumption of individual drivers while driving for 100 km and consequently on total fuel consumption. The amount of the consumed fuel was detected by a simple method based on refuelling into the vehicle tank at the end of each working day of the driver. The fuel consumption report showed how many litres of fuel were refuelled at the gas station to the vehicle. This method is based on the amount of gas pumped into the main tank of the vehicle (l) during the monitored period and also on the number of kilometres travelled by the vehicle (km) during the monitored period.

Because in the winter months it is necessary to heat the vehicle while air temperatures are different for each day, the amount of fuel consumption was calculated according to eq. (1), which excludes differences in fuel consumption between drivers caused by the consumption of fuel for heating and heating of the vehicle.

$$Sp_2 = \frac{V - V_{vo}}{L} \cdot 100 , \tag{1}$$

where Sp_2 – fuel consumption on a ride, $l \cdot (100\ km)^{-1}$;

V – volume of refuelled diesel, l;

V_{vo} – volume of diesel consumed for heating of the vehicle, l;

L – distance travelled by the vehicle, km.

For heating and warming up of Bus 1 – CNG fuel was not consumed as heating and warming up of the vehicle is not designed for burning of compressed natural gas.

The amount of fuel calculated according to eq. (1) was compared with the amount of fuel recorded by the flow meter Adast Js6 8500.06, Fig. 1.

A simplified relationship can be used to calculate the fuel consumption by using the flow meter:

$$Sp_{100} = \frac{m_p - P_e}{3.6.10^4 . \rho_p . v} , \tag{2}$$

where S_{p100} – fuel consumption for 100 km, $l \cdot (100\ km)^{-1}$;

m_p – specific consumption of the engine, $g \cdot (kW \cdot h)^{-1}$;

P_e – efficient engine performance, kW;

ρ_p – specific weight of fuel, $kg \cdot dm^{-3}$;

v – vehicle speed, $km \cdot h^{-1}$.

Specific consumption of the engine can be determined from the RPM curve. This fuel consumption indicator was involved in the fuel delivery system of the vehicle [5].

The flow meter Adast was calibrated in advance, and the values were measured during calibration, as it can be seen in Table 1.

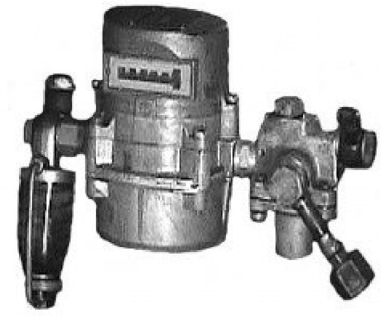

Fig. 1. **Flow meter Adast Js6 8500.06 [6]**

The difference between the measured values according to eq. (1) and the flow meter Adast was approximately 2.2 %. However, this imprecision meets the 3 % tolerance declared by the manufacturer.

The average fuel consumption per month was calculated by the arithmetic mean (3). The results were inscribed into the table.

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{1}{n} \sum_{i=1}^{n} x_i . \tag{3}$$

In calculation of the average fuel consumption per month the extreme values did not occurr. Therefore, it was possible to exclude this statistical method at calculating the average fuel consumption per month.

Table 1

Measured and calculated values during calibration of the flow meter Adast

Number of measurements	Time, s	Pump speed, min^{-1}	Delivery of fuel	Volume of fuel in measuring cylinder, ml	Total volume of fuel – flow meter, dm^3	Difference between measuring cylinder and flow meter, %	Total volume of fuel – PC, dm^3	Difference between flow meter and PC, dm^3	Calculated flow rate - measuring cylinder, $dm^3 \cdot h^{-1}$	Calculated flow rate – PC
1	300	702	min.	175	0.175	0.000	0.176	0.001	2.1	2.16
2	300	702	min.	175	0.175	0.000	0.174	-0.001	2.1	2.16
3	300	702	min.	180	0.175	2.857	0.176	0.001	2.16	2.16
4	300	702	min.	180	0.175	2.857	0.174	-0.001	2.16	2.16
5	300	702	min.	176.5	0.174	1.437	0.174	0	2.12	2.16
Average	300	702		177.3	0.175	1.43	0.1748	0	2.13	2.16
Max. value						2.86	0.176	0.001		
Dispersion						2.04		0		
Standard deviation						1.43		0.001		
6	90	702	max.	225	0.228	-1.316	0.231	-0.003	9	9.36
7	90	702	max.	225	0.227	-0.881	0.233	0	9	9.36
8	90	702	max.	225	0.226	-0.442	0.229	0.003	9	9.36
9	90	702	max.	225	0.228	-1.316	0.231	0.003	9	9.36
10	90	702	max.	225	0.229	-1.747	0.228	-0.001	9	9.36
Average	90	702		225	0.228	-1.14	0.2304	0	9	9.36
Max. value						-1.75	0.229	0.006		
Dispersion						0.25		0		
Standard deviation						0.5		0.002		

Differences between the driving modes of the drivers were determined. The data obtained were processed by a quantitative method and verified by a qualitative analysis.

Subsequently, the recording sheets for the drivers were created consisting of data on total kilometres, bus drivers, average fuel consumption per 100 km and total fuel consumption. The sheets were created for each driver for the period November 2014 to October 2015. The data obtained were progressively recorded on these sheets by the person responsible. The survey lasted for one year, and the values measured with both drivers were mutually compared.

Results and discussion

Data recorded after each working day were filled in the record sheets corresponding to each month throughout the year. They are shown in the recording sheets as achievements of the bus driver A and of the bus driver B. Since the survey was conducted during the period November 2014 to October 2015, 12 record sheets were completed. The resulting values of the 12 recording sheets were written into the final table, consisting of the monitored parameters of the driver A and of the driver B on a monthly basis during the period November 2014 to October 2015, see Table 2.

Table 2

Final table of monitored parameters from November 2014 to October 2015

		Month	Total number of travelled kilometers	Total fuel consumption according to Norm, l	Total fuel Consumption, l – real	Heating and warming-up, l	Difference between standardized and real fuel consumption, l	Average fuel consumption, l·(100 km)$^{-1}$	Total fuel consumption without heating and warming-up, l	Average fuel consumption per ride, l·(100 km)$^{-1}$
Bus 1 – CNG	Driver A	11/14	2 789	976.15	991.76	0.00	-15.61	35.94	991.76	35.94
		12/14	2 046	716.10	735.59	0.00	-19.49	36.16	735.59	36.16
		01/15	3 606	1 262.10	1 274.40	0.00	-12.30	35.51	1 274.40	35.51
		02/15	2 586	905.10	917.53	0.00	-12.43	35.66	917.53	35.66
		03/15	2 824	988.40	988.92	0.00	-0.52	35.12	988.92	35.12
		04/15	3 209	1 123.15	1 121.77	0.00	1.38	35.07	1 121.77	35.07
		05/15	3 586	1 255.10	1 260.45	0.00	-5.35	35.42	1 260.45	35.42
		06/15	3 663	1 282.05	1 287.66	0.00	-5.61	35.54	1 287.66	35.54
		07/15	1 752	613.20	604.01	0.00	9.19	34.46	604.01	34.46
		08/15	2 756	964.60	973.12	0.00	-8.52	35.35	973.12	35.35
		09/15	3 175	1 111.25	1 118.23	0.00	-6.98	35.31	1 118.23	35.31
		10/15	3 204	1 121.40	1 128.97	0.00	-7.57	35.34	1 128.97	35.34
		Total	35 196	12 318.60	12 402.41	0.00	-83.81	35.41	12 402.41	35.41
Bus 2 – Diesel	Driver B	11/14	2 280	735.60	749.29	38.00	-13.69	33.36	711.29	31.57
		12/14	2 532	824.74	852.07	73.00	-27.33	34.00	779.07	31.00
		01/15	2 207	735.46	754.37	69.00	-18.91	34.32	685.37	31.23
		02/15	2 182	735.17	756.89	59.00	-21.72	35.06	697.89	32.22
		03/15	2 627	811.80	817.29	23.00	-5.49	31.43	794.29	30.47
		04/15	2 580	767.40	770.56	4.00	-3.16	30.06	766.56	29.90
		05/15	2 715	801.99	799.84	0.00	2.15	29.65	799.84	29.65
		06/15	2 070	611.16	607.74	0.00	3.42	29.60	607.74	29.60
		07/15	2 250	640.47	636.47	0.00	4.00	28.46	636.47	28.46
		08/15	2 115	584.00	592.90	0.00	-8.90	28.38	592.90	28.38
		09/15	2 934	865.26	877.40	20.00	-12.14	30.19	857.40	29.47
		10/15	2 341	739.71	763.19	45.00	-23.48	32.90	718.19	30.92
		Total	28 833	8 852.76	8 978.01	331.00	-125.25	31.45	8 647.01	30.24

Recording sheets indicated that they travelled 64 029 km all together and 21 380.42 l of fuel were consumed, while 21 171.36 l supposed to be consumed according to the company's assumption. The driver A travelled 35 196 km which represents 55 % of the total number of the travelled kilometres and the driver B travelled 28 833 km which represents 45 % of the total number of the travelled kilometres. The difference of the travelled kilometres between the drivers is 6 363 km. The travelled kilometres per month recorded for both bus drivers are presented in Fig. 2. The driver A supposed to reach 12 318.60 l of compressed natural gas (CNG) per travelled kilometres while his measured fuel consumption was 12,402.41 l, which is representing an overrun of the estimated fuel consumption by 0.68 %. For heating and warming up of the vehicles fuel was not consumed as heating and warming up of the vehicle is not designed for burning of compressed natural gas. The driver B supposed to reach 8 852.76 l of fuel consumption per travelled kilometres. His measured fuel consumption was 8 978.01 l, which is representing an overrun of the estimated fuel consumption by 1.41 %. This consumption includes 331 l of fuel used for heating and warming-up of the vehicle. Fuel consumption without heating and warming-up was 8 647.01 l, which is the fuel consumption determined for driving only, which represents 96.3 %.

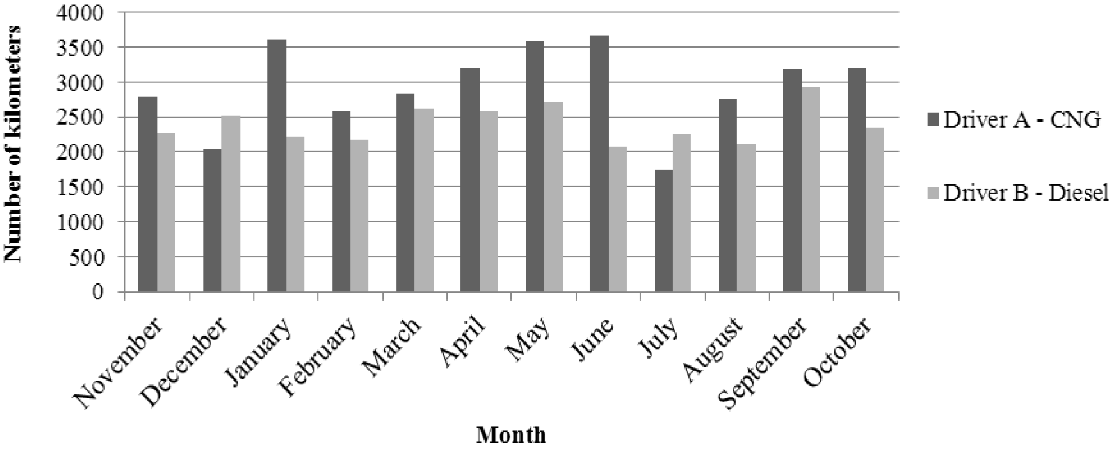

Fig. 2.**Travelled kilometers per month**

Fig. 2 indicates that the driver B only in December 2014 and July 2015 drove more kilometers than the driver A. In the remaining months of the period the number of kilometers was dominated by the driver A, which was also reflected in the total number of kilometers.

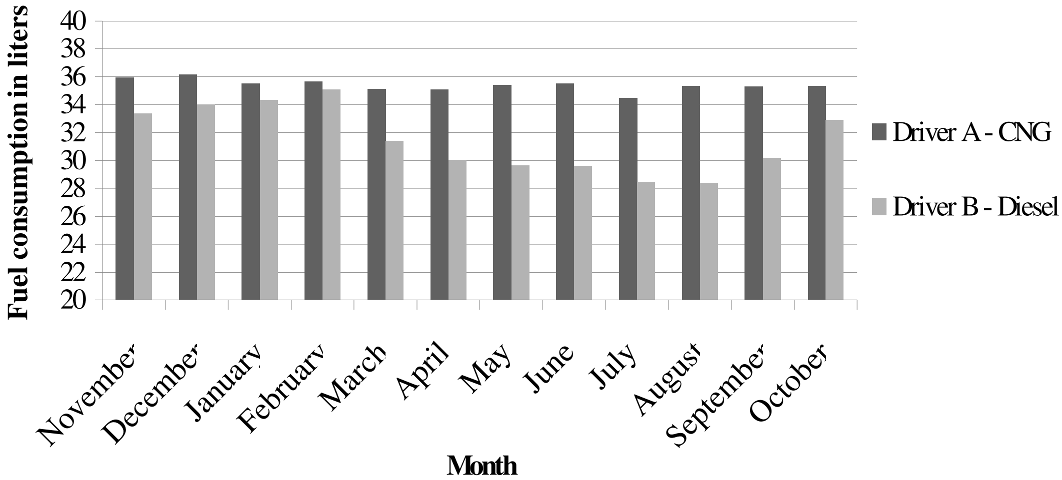

Fig. 3. **Average fuel consumptions per month**

Fig.3indicates that the driver A reached approximately the same average fuel consumption per 100 kilometres in the long term. Driver B had the highest average monthly fuel consumption especially in the winter months. The decrease in the average monthly fuel consumption reaches mainly in the summer months. According to [7] the use of compressed natural gas in transport is a good solution mainly for environmental performance, but also an economic perspective in terms of fuel prices. CNG does not contain solid particles and therefore has better emission values. At a lower cost per litre of fuel there is economy of operation in terms of fuel consumption better. According to [8] it is necessary to take into account the economy of operation in terms of service intervals and initial costs on transformation of vehicles or the purchase of new CNG vehicles. Service inspections and repairs are in CNG vehicles significantly more expensive than for conventional vehicles to diesel.

Conclusions

We can assess that both drivers riding on a city bus service reached overrun of the fuel consumption. The driver A achieved an overrun of fuel consumption 83.81 liters of CNG and the driver B 125.25 liters of diesel. The higher fuel consumption was achieved during the winter months. Overrun of fuel consumption of both city buses is likely to be caused by frequent stops for vehicles on pick up of passengers and then it is due primarily to the waiting time at traffic lights and demurrage in the frequent traffic jams. Although in both cases there was over-consumption, the assumptions of the transport company were confirmed by performing the survey. But do not forget that this is only the operational efficiency of fuel consumption. At a price 0.625 EUR/1Kg CNG and 0.790 EUR/1l of diesel it can assess that better fuel economy exhibits a bus, which was rebuilt on combustion of compressed natural gas (CNG) because the operation cost at one kilometer represents EUR 0.19, while a bus with classic diesel engine EUR 0.24. At the distance, for example, 30 000 km there is a change to saving of 21 % in favor of CNG.

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