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Comparison of methods for fuel consumption measuring of vehicles

J. Pavlu*, V. Jurca, Z. Ales and M. Pexa

Czech University of Life Sciences Prague, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamycka 129, 165 21 Prague 6, Czech Republic
*Correspondence: jindrichpavlu@seznam.cz

Abstract. Essential task for companies in these days is to reduce operating costs and optimization of workflow processes of machines, in order to increase the competitiveness and productivity. Telematics systems is relatively widespread and utilized for fleet management and enables collecting a wide range of operating parameters. One of the monitored parameters of operating costs is fuel consumption of machines. The collection of data on fuel consumption can be realized using various methods. By default, the fuel consumption data is transmitted from CAN–BUS which does not always coincide with the value of the real fuel consumption. Another possible way of fuel consumption monitoring is realized via installation of capacitance probe mounted directly into the fuel tank. The principle of measurement of these two methods is different, and each method has its own specifics. For instance, a capacitive probe enables detection of non-standard decreases of fuel level in the fuel tank. The aim of this paper is to compare the methods of fuel consumption measuring via the CAN–BUS and utilization of capacitive fuel probe. Measuring unit Gcom was used for collecting data which sends data of fuel consumption to the server in real–time. The purpose of this paper is to prove or disprove the hypothesis that measured fuel consumption is statistically significant between measuring via CAN-BUS compared to capacitance probe.

Key words: Fuel consumption, capacitance probe, CAN-BUS, telematics system.

INTRODUCTION

There are various methods for measuring fuel consumption, which are based on detection of the fuel level in fuel tank. These methods for example include measurements using mechanical floats, ultrasonic sensors, digital rulers with mechanical float, pressure sensors, relay floats. Mentioned methods of measuring fuel level have a number of disadvantages. Mechanical floats are often unreliable due to the use of mechanical components. Ultrasonic sensors may have difficulty with obtaining a proper signal at wavy surface of fuel level and are also more expensive. Pressure sensors have problems with the accuracy of measurement when overpressure occurs in the fuel tank due to temperature changes. Measuring accuracy of relay floats is relatively low (Partner mb, 2010).

Nowadays transport companies routinely use mainly two ways of measuring fuel consumption with respect to the acquisition price, reliability, accuracy of measuring and control of unfair methods of treating fuels.

By default, the fuel consumption data is transmitted from CAN–BUS which does not always coincide with the value of the real fuel consumption. Another possible way of fuel consumption monitoring is realized via installation of capacitance probe mounted directly into the fuel tank (Li & Fan, 2007). The principle of measurement of these two methods is different, and each method has its own specifics. For instance, a capacitive probe enables detection of non-standard decreases of fuel level in the fuel tank.

The data from both of these methods are transferred telematics systems and via web interface are available in real time (Daniel et al., 2011).

The purpose of this paper is to prove or disprove the hypothesis that measured fuel consumption is statistically significant between these two methods. Whether, there is the difference between fuel consumption measured via CAN–BUS compared to capacitance probe.

MATERIALS AND METHODS

Telematics system is an eminent technology which merges telecommunications and informatics. This blending of wireless telecommunication technologies along with computers is done ostensibly with the goal of conveying information over vast networks to handle vehicle information. The entire system consists of TeCU (Telematics Control Unit) which is called Gcom, server and webpage application to monitor and to sense ample information's received from vehicle. Telematics Control Unit (TeCU) has to be designed and developed, which could be used in real time and off time monitoring, tracking and reporting system (Dhivyasri et al., 2015).

Data about fuel level in the tank were transmitted each 120 s from capacitance probe CAP04. From the CAN–BUS were transmitted data with the same period, but fuel rate was recorded by Gcom each 1 s.

Observed vehicles for experiment were chosen from a transport company, which has a vehicle fleet of 150 vehicles. From the total number of vehicles were selected vehicles with operating time of more than 60,000 km over a period of six months.

Records from vehicle re–fueling were compared with data measured by capacitance probe. The differences were up to ± 1% which is not statistically significant.

Vehicle brands were not compared among each other because of different variation of driving style of individual drivers, difficultness of route (highway, urban condition, etc.) and differing amounts of cargo transported.

Principle of measuring fuel consumption via CAN-BUS

It seems as a convenient solution is obtaining information about fuel consumption via CAN–BUS. This information is contained in the messages of engine diagnostic interface or in the messages of on–board bus of vehicles.

Currently, majority of truck manufacturers voluntarily comply the standardization in field CAN–BUS according to the standard SAE J1939 or standardized format FMS (Fleet Management System) gateway. These standards contain information about the instantaneous fuel rate to the engine (ACEA Working Group HDEI/BCEI, 2012).

Before using these data, it is necessary to be aware of how these data are collected in the truck. Instantaneous fuel rate depends on the designers of engine control system. Usually instantaneous fuel rate is measured by length of the injection and it is conversion to fuel rate.

CAN protocol uses two types of data messages. The first type is defined by specifications 2.0A (Standard Frame), while 2.0B specification defines Extended Frame (J1939). The only significant difference between the two these formats is the length of the message identifier which is 11 bits for a Standard Frame and 29 bits for the Extended Frame.

The data link layer describes the general characteristics of the CAN–BUS as a structure of data frame identification, transport protocol for transmitting messages that contain more than 8 bytes and encoding parameter groups.

Standard SAE J1939–71 (Vehicle Application Layer) defines groups of parameters and contained therein signals, for example engine coolant temperature, engine oil temperature, fuel rate etc. Groups of current parameters are transmitted in the data message. Each group of parameters is defined by a unique PGN (Parameter Group Numbers) (Fig. 1). This number consists of two parts in the message identifier. The first part is the PDU format and the second is a specific PDU.

0x00FEF2					PGN Hex
65,266					PGN
100 ms					Rep. Rate
Data Byte 1	**Data Byte 2**	**Data Byte 3**	**Data Byte 4**	**Data Byte 5-8**	Byte No.
8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1	8 7 6 5 4 3 2 1		Bit No.
Fuel Rate	Fuel Rate	Instantaneous Fuel Economy	Instantaneous Fuel Economy	Not used for (BUS) FMS standard	Name Name
0.05 l h^{-1} per bit	0.05 l h^{-1} per bit	1 512^{-1} km l^{-1} per bit	1 512^{-1} km l^{-1} per bit		Values
0 offset	0 offset	0 offset	0 offset		Values
0 to 3,212.75 l h^{-1}	0 to 3,212.75 l h^{-1}	0 to 125.5 km l^{-1}	0 to 125.5 km l^{-1}		Values
SPN 183	SPN 183	SPN 184	SPN 184		SPN

Figure 1. Parameters CAN-BUS according SAE J1939 (ACEA Working Group HDEI/BCEI, 2012).

Principle of measuring of fuel level in the tank by the capacitance probe CAP04

The principle of measuring of fuel level by the capacitance fuel level sensor is based on the fact that diesel is electrically non–conductive liquid. Capacitive probe CAP04 consists of two tubes of different diameter, which are the electrodes of capacitor. The dielectric is composed of electrically non-conductive material, specifically with a fuel and air. The relative permittivity of air is $\varepsilon_r = 1$, during refuelling the air is replaced with diesel which has relative permittivity $\varepsilon_r = 2$ and due to this fact the capacity of the capacitor increases. The capacitive sensor measures the position of the boundary between air and diesel fuel (Fig. 2). (Partner mb, 2010)

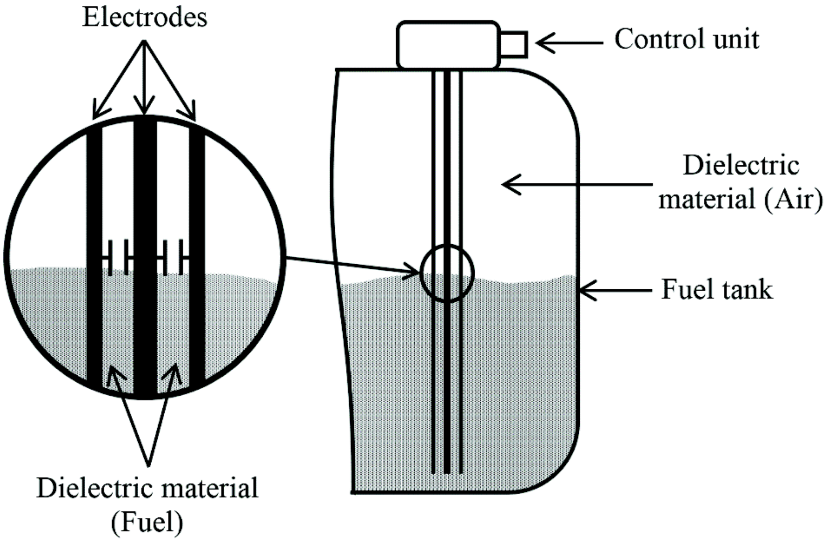

Figure 2. Principle of measuring of fuel level in the tank by the capacitance probe.

The probe is also equipped with thermometers to sense temperature of fuel and the surface temperature of the fuel tank. The processor evaluates data according to the actual capacity of the probe to match the measured volume of diesel at a reference temperature 15 °C. This method ensures that the reported amounts of fuel are not distorted by thermal expansion of diesel. Furthermore, the probe measures the tilt of the tank in two axes. While driving terrain when the level of diesel fluctuates rapidly and strongly, the probe indicates stable signal by means of appropriate filters of the signal.

Before installing the fuel probes the accuracy of measurement of the probe was tested at temperatures from -15 °C to +55 °C. Samples of diesel from three different fuel suppliers (Shell, Slovnaft, OMV) were used for testing. The highest deviation of measurement was measured on a sample from Shell at 13 °C – deviation was 0.21%. (Pavlu et al., 2013; Ales et al., 2015).

Experiment involved five brands of truck manufacturers (Scania R 440 Volvo FH 460, MAN TGX 480, DAF XF 460, Renault Kerax 420). Each brand was represented by fifteen trucks. Vehicles were operated primarily in companies focused on road transport and freight forwarding in Central and Eastern Europe. The observation period of operation of trucks was determined for the second half of year 2015. Average distance travelled of one truck was around 80,000 kilometres. The observation period truck traffic was relatively short, and therefore effects of wear on the fuel system was neglected.

RESULTS AND DISCUSSION

Collected data from telematics system must always be properly processed. VBA code was used to process the raw data. Data were sorted out and filtered under specific conditions. Proceed data show cumulative fuel consumption. Raw data of one vehicle (6 months period) had approximately 50,000 records. Data on fuel consumption measured via CAN–BUS are in incremental format and do not include information about refuelling. Calculation of cumulative trend of consumption is simple (dotted line in Fig. 3). In terms of capacitance probe each user has continuous information about consumption and refuelling (referenced to the distance travelled). This data represents a saw–tooth pattern in (Fig. 3). Such data must be converted into cumulative form. For this purpose, a code in Visual Basic for Applications was created. Program code can reliably distinguish between consumption and refuelling or other factors as may be fuel tank tilting or fuel theft. The linear trend of cumulative consumption with linear equation (Fig. 3). Slope of linear equation represents consumption of a heavy truck for 1 kilometre. Multiplying slope of linear equation of the line 100 times, it is possible to obtain a commonly used form of fuel consumption in litres per 100 kilometres.

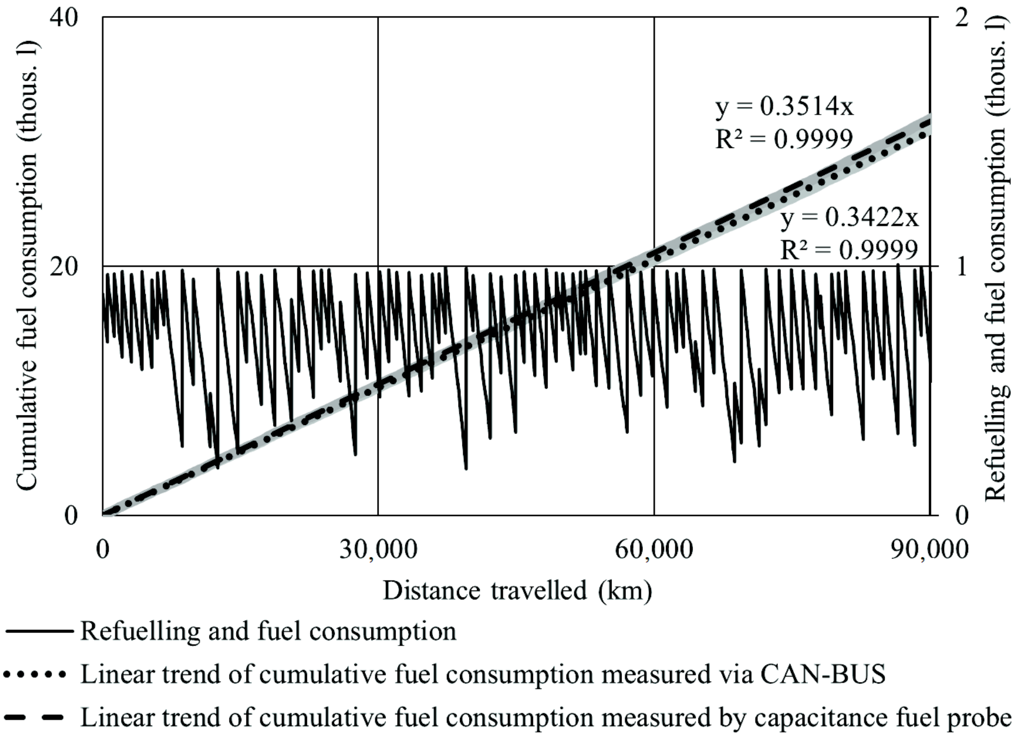

Figure 3. Measured and calculated data of fuel consumption - Scania R 440 No. 1.

Results calculated from obtained data are for each brand of vehicles (Tables 1–5). Results show the specific values of fuel consumption, both from the CAN–BUS and capacitance probe. The last column shows the difference between the fuel consumption compared methods in the tables.

Table 1. Results of calculated data from telematics system– Scania R 440

Number of vehicle	Distance travelled (km)	Fuel consumption CAN-BUS ($l\ 100\ km^{-1}$)	Fuel consumption capacitance probe ($l\ 100\ km^{-1}$)	Difference of fuel consumption ($l\ 100\ km^{-1}$)
1*	**90,089**	**34.215**	**35.141**	**0.9262**
2	78,144	34.335	35.151	0.8160
3	80,359	33.102	34.030	0.9280
4	66,486	36.746	37.553	0.8070
5	75,745	34.200	35.053	0.8526
6	92,316	33.709	34.377	0.6677
7	86,849	33.876	34.339	0.4630
8	75,802	33.723	34.515	0.7916
9	66,061	35.835	36.532	0.6965
10	94,989	34.186	34.760	0.5743
11	76,393	35.887	36.639	0.7521
12	89,742	36.067	36.933	0.8660
13	65,732	33.435	34.074	0.6394
14	86,561	35.658	36.386	0.7275
15	74,248	35.310	35.737	0.4272

* - measured and calculated data of fuel consumption (Fig. 2).

Table 2. Results of calculated data from telematics system – VOLVO FH 460

Number of vehicle	Distance travelled (km)	Fuel consumption CAN-BUS ($l\ 100\ km^{-1}$)	Fuel consumption capacitance probe ($l\ 100\ km^{-1}$)	Difference of fuel consumption ($l\ 100\ km^{-1}$)
1	63,510	36.824	37.487	0.663
2	66,250	35.587	36.152	0.565
3	62,837	33.370	33.837	0.467
4	63,332	35.397	36.402	1.005
5	64,789	34.647	34.852	0.205
6	70,234	37.466	38.203	0.737
7	84,443	37.048	37.593	0.545
8	95,294	32.077	32.954	0.877
9	71,327	35.453	36.319	0.866
10	62,633	32.450	33.369	0.919
11	63,665	37.147	37.670	0.523
12	84,338	33.804	34.530	0.726
13	93,061	34.390	34.896	0.506
14	86,843	37.968	38.736	0.768
15	64,758	33.457	34.334	0.877

Table 3. Results of calculated data from telematics system – MAN TGX 480

Number of vehicle	Distance travelled (km)	Fuel consumption CAN-BUS ($l\ 100\ km^{-1}$)	Fuel consumption capacitance probe ($l\ 100\ km^{-1}$)	Difference of fuel consumption ($l\ 100\ km^{-1}$)
1	77,851	37.080	37.264	0.1839
2	65,719	35.652	36.147	0.4948
3	63,104	37.184	37.954	0.7697
4	68,936	34.539	35.526	0.9873
5	63,756	33.149	33.824	0.6745
6	63,413	35.001	35.705	0.7039
7	77,878	37.717	38.360	0.6431
8	62,754	37.838	38.764	0.9257
9	63,182	33.926	34.616	0.6903
10	64,080	35.486	36.009	0.5228
11	93,819	35.117	35.630	0.5133
12	71,457	33.241	33.799	0.5580
13	84,717	36.605	37.466	0.8614
14	70,055	36.324	37.316	0.9919
15	69,348	36.510	37.120	0.6096

Table 4. Results of calculated data from telematics system – DAF XF 460

Number of vehicle	Distance travelled (km)	Fuel consumption CAN-BUS ($l\ 100\ km^{-1}$)	Fuel consumption capacitance probe ($l\ 100\ km^{-1}$)	Difference of fuel consumption ($l\ 100\ km^{-1}$)
1	84,010	33.475	34.181	0.7062
2	74,061	34.854	35.442	0.5882
3	80,967	32.964	33.911	0.9465
4	63,184	37.894	38.651	0.7567
5	83,840	34.537	35.122	0.5854
6	71,348	37.954	38.553	0.5986
7	95,672	32.934	33.718	0.7839
8	67,330	37.895	38.776	0.8806
9	94,342	35.049	35.635	0.5864
10	70,258	37.684	38.471	0.7873
11	63,179	32.570	33.223	0.6532
12	97,545	35.949	36.543	0.5942
13	89,319	36.318	37.135	0.8167
14	86,689	34.286	34.931	0.6453
15	81,650	36.515	37.085	0.5697

Table 5. Results of calculated data from telematics system – Renault Kerax 420

Number of vehicle	Distance travelled (km)	Fuel consumption CAN-BUS ($l\ 100\ km^{-1}$)	Fuel consumption capacitance probe ($l\ 100\ km^{-1}$)	Difference of fuel consumption ($l\ 100\ km^{-1}$)
1	77,187	32.260	32.989	0.7286
2	91,602	38.181	39.146	0.9647
3	63,225	32.133	32.748	0.6146
4	85,157	36.544	37.414	0.8698
5	91,953	35.289	35.874	0.5845
6	84,998	33.098	33.885	0.7865
7	93,115	35.468	35.879	0.4112
8	96,863	35.236	35.894	0.6580
9	79,693	33.807	34.548	0.7410
10	94,249	33.812	34.649	0.8371
11	82,134	37.496	38.465	0.9689
12	96,707	33.552	34.110	0.5583
13	93,037	33.378	34.209	0.8312
14	85,378	35.406	36.291	0.8848
15	94,704	34.844	35.325	0.4809

From the calculated data can be determined null hypothesis H_0: there is no statistically significant difference between consumption measured via CAN–BUS and capacitance probe. Wilcoxon Signed–Rank non-parametric test (Equation 1–2) was used to verify this hypothesis (Mosna, 2015). Significance level was set at $\alpha = 0.05$ and two-tailed hypothesis was chosen.

$$Z = \frac{\min\left(W^{+};W^{-}\right) - \frac{1}{4} n \cdot (n+1)}{\sqrt{\frac{1}{24} n \cdot (n+1) \cdot (2n+1)}} \tag{1}$$

$$Z = \frac{\min(2{,}850;0) - \frac{1}{4} 75 \cdot (75+1)}{\sqrt{\frac{1}{24} 75 \cdot (75+1) \cdot (2 \cdot 75+1)}} = -7.52479 \tag{2}$$

where: W – sum of the signed ranks ($^{+}$positive, $^{-}$ negative); n – sample size.

The Z-value is -7.52479. The p-value is 0. The result is significant at $P \leq 0.05$. That can be concluded that null hypothesis H_0 is rejected. Therefore, there is statistically significant difference between consumption measured via CAN-BUS and capacitance probe.

All results of difference between fuel consumption measured via CAN-BUS and capacitance probe are shown in box plot in Fig. 3. The average difference between compared methods for all trucks under consideration was 0.7 l 100 km^{-1} of fuel consumption.

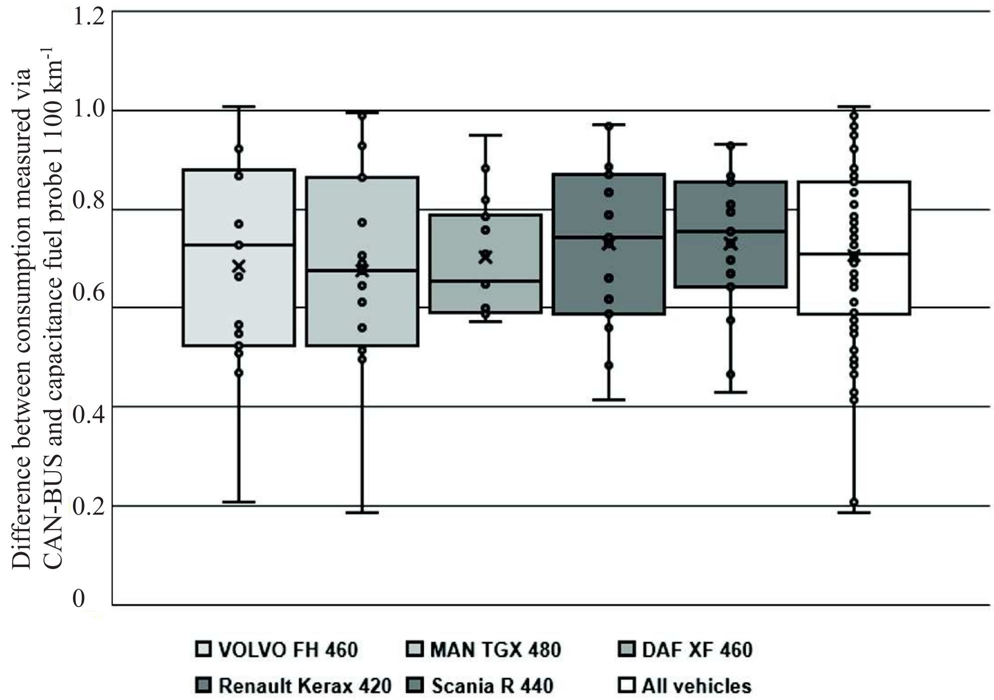

Figure 3. Box plot representing measured Difference between consumption measured by capacitance probe and CAN–BUS.

CONCLUSIONS

The aim of the paper was to prove or disprove the hypothesis, if there is statistically significant difference between described methods of measuring fuel consumption.

Designed experiment involved 75 trucks. Trucks were operated primarily in companies focused on road transport and freight forwarding in Central and Eastern Europe. The observation period of operation of trucks was determined for 6 months. Average distance travelled of one truck was around 80,000 kilometers. Fuel consumption was monitored for each truck using two methods via CAN–BUS compared to capacitance probe. Collected data was transmitted through telematics system and then processed based on an algorithm created in Visual Basic for Applications. Results were statistically processed in order to accept or reject the hypothesis. Null hypothesis H_0 was rejected, it means, there is statistically significant difference between consumption measured via CAN–BUS compared to capacitance probe. Created box plot shows that average difference between compared methods for all trucks under consideration was

0.7 l 100 km^{-1} of fuel consumption. The results confirm that the fuel consumption measured via CAN–BUS shows lower values compared to real fuel consumption.

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