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Measurement of vehicle emissions in real road conditions Part I. Methodology for measuring emissions from vehicles

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Abstract. Over the past 30–40 years, vehicle tailpipe emissions of particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HCs) have decreased significantly. Advanced emission after-treatment technologies have been developed for gasoline and diesel vehicles to meet increasingly stringent regulations, yielding absolute emission reductions from the fleet despite increased vehicle travel. Passenger cars are an important source of air pollution, especially in urban areas. Recently, real-driving emissions (RDE) test procedures have been introduced in the EU aiming to evaluate nitrogen oxides (NOx) and particulate number (PN) emissions from passenger cars during on-road operation. Although RDE accounts for a large variety of real-world driving, it excludes certain driving situations by setting boundary conditions (e.g., in relation to altitude, temperature or dynamic driving). The present work investigates the on-road emissions of NOx, NO2, CO, particle number (PN) and CO2 from a vehicles, including diesel, gasoline, liquid petroleum gas (LPG) and compressed natural gas (CNG) vehicles. The vehicles were tested under different on-road driving conditions outside boundaries. These included 'baseline' tests, but also testing conditions beyond the RDE boundary conditions to investigate the performance of the emissions control devices in demanding situations.

INTRODUCTION

As urbanization accelerates, transport-related environmental issues deteriorate. The report of Intergovernmental Panel on Climate Change (IPCC) shows that 20–30% of total greenhouse gases (GHGs) are released from urban transportation operation including passenger and freight transportation [1]. Estimating and visualizing fuel consumption and emissions from transportation provide an understanding of the energy cost and air pollution caused by travel or transportation. However, previous studies often estimated fuel consumption/emissions without considering vehicles' activities and thus might lead to erroneous estimations. Therefore, this study proposes approaches that estimate and visualize vehicles' fuel consumption/emissions accurately by considering vehicles' mobile and stationary activities in a space-time-integrated framework

Vehicles are tested in controlled and relatively narrow laboratory conditions to determine their official emission values and reference fuel consumption. However, on the road, ambient and driving conditions can vary over a wide range, sometimes causing emissions to be higher than those measured in the laboratory. For this reason, the European Commission has developed a complementary Real-Driving Emissions (RDE) test procedure using the Portable Emissions Measurement Systems (PEMS) to verify gaseous pollutant and particle number emissions during a wide range of normal operating conditions on the road. This paper presents the newly-adopted RDE test procedure, differentiating six steps: 1) vehicle selection, 2) vehicle preparation, 3) trip design, 4) trip execution, 5) trip

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verification, and 6) calculation of emissions. Of these steps, vehicle preparation and trip execution are described in greater detail. Examples of trip verification and the calculations of emissions are given [2]. The gap between official laboratory results and the actual on-road emissions led to a revision of the type approval requirements in the EU [3].

BACKGROUND

The ingredients of air pollution

Cars, trucks and buses produce air pollution throughout their life cycle, including pollution emitted during vehicle operation and fuel production. Additional emissions are associated with refining and distribution of fuels and to a lesser extent, manufacturing and disposal of the vehicle.

Air pollution from cars, trucks and buses is split into primary and secondary pollution. Primary pollution is emitted directly into the atmosphere; secondary pollution results from chemical reactions between pollutants in the atmosphere. Fetuses, newborn children, and people with chronic illnesses are especially susceptible to the effects of air pollutants. The following are the major pollutants from motor vehicles:

Particulate matter (PM). One type of particulate matter is the soot seen in vehicle exhaust. Fine particles — less than one-tenth the diameter of a human hair — pose a serious threat to human health, as they can penetrate deep into the lungs. PM can be a primary pollutant or a secondary pollutant from hydrocarbons, nitrogen oxides, and sulfur dioxides. Diesel exhaust is a major contributor to PM pollution.

Volatile Organic Compounds (VOCs). These pollutants react with nitrogen oxides in the presence of sunlight to form ground level ozone, a main ingredient in smog. Though beneficial in the upper atmosphere, at the ground level this gas irritates the respiratory system, causing coughing, choking, and reduced lung capacity. VOCs emitted from cars, trucks and buses — which include the toxic air pollutants benzene, acetaldehyde, and 1,3-butadiene — are linked to different types of cancer.

Nitrogen oxides (NO_x). These pollutants form ground level ozone and particulate matter (secondary). Also harmful as a primary pollutant, NO_x can cause lung irritation and weaken the body's defenses against respiratory infections such as pneumonia and influenza.

Carbon monoxide (CO). This odorless, colorless, and poisonous gas is formed by the combustion of fossil fuels such as gasoline and is emitted primarily from cars and trucks. When inhaled, CO blocks oxygen from the brain, heart, and other vital organs.

Sulfur dioxide (SO_2). Power plants and motor vehicles create this pollutant by burning sulfur-containing fuels, especially diesel and coal. Sulfur dioxide can react in the atmosphere to form fine particles and, as other air pollutants, poses the largest health risk to young children and asthmatics.

Greenhouse gases. Motor vehicles also emit pollutants, predominantly carbon dioxide, that contribute to global climate change. In fact, tailpipe emissions from cars, trucks and buses account for over one-fifth of the United States' total global warming pollution; transportation, which includes and airplanes, trains and ships accounts for around thirty percent of all heat-trapping gas emissions [4, 8].

In order to determine compliance with environmental regulations, it is necessary to perform appropriate tests. In the last decades, vehicles have been tested in controlled laboratory environments to establish official emissions values according to pre-established driving cycles. However, there has been mounting evidence of the divergence between real life emissions and what could be expected according to these laboratory tests. This unsatisfactory situation has partly been linked to the shortcomings of the standardized tests used for type approval (the New European Driving Cycle adopted in most countries in the world, as well as other tests such as the FTP 75 in the United States or the JS-08) and the in-service conformity testing. The Volkswagen scandal has increased awareness and created a sense of urgency regarding the need to have appropriate tests that ensure that environmental regulations are effectively enforced and consumer confidence restored [5].

The establishment of the cities as an attractive centers for work and life has led to their expansion and increasing their population. Due to the large distances between the residential areas, workplaces, public attraction centers and various opportunities to the citizens, they have to move within the city in various ways. Of all the types of public transport only the taxi transport allows flexibility and choice of random destination, pick up and drop off point and the client is served at the highest level. The taxi services are operated by vehicles with diesel and gasoline engines, which most often can work with LPG or CNG [6].

PREREQUISITES AND MEANS FOR SOLVING THE PROBLEM

The European Environmental Agency has also pointed out that the increased divergence between official carbon dioxide emissions, as measured by laboratory-based official tests, and real fuel consumption has been a major concern undermining policies to reduce the environmental impact of transport by establishing increasingly stringent targets for average emissions. The discrepancy between laboratory tests and real world values was initially the same for both diesel and petrol cars but since 2010 the gap was higher for diesel vehicles, being around 5 per cent greater than for petrol vehicles [5].

MATERIALS AND METHOD

This paper develops methodologies and describes the necessary technical equipment for measuring the exhaust components in the exhaust gases during the movement of vehicles in real road conditions in urban environments. Two vehicles with the following characteristics were used to perform the measurements:

- - Citroen Jumpy - a petrol-powered light commercial vehicle shown in Figure 1a. In addition, the vehicle is equipped with two systems ensuring the operation of the engine with LPG and CNG. For this purpose, two additional tanks are shown in the cargo space of the vehicle, shown in Figure 1b, for fuel storage for both additionally installed systems that ensure the operation of the engine with different gaseous fuels. This allows the engine to run unsimultaneously with three types of fuel - gasoline, liquid petroleum gas (LPG) and compressed natural gas (CNG).
- Skoda Fabia – a diesel-powered car shown in Figure 1c.

(a) (b) (c)

FIGURE 1. Tested vehicles (a)-Citroen Jumpy, (b) - Additional tanks for LPG and CNG (c) -Skoda Fabia.

The technical characteristics of the vehicles used in the measurements are presented in Table 1. Both vehicles have the Emission standard Euro4.

TABLE 1 Technical data of the experimental vehicles

Model:	Citroen Jumpy Combi L1H1 2.0	Skoda Fabia II 1.4 TDI
Body style:	Minivan / MPV	
Production period:	2006. January ... 2012. January	2007 January…2010 Mart
Engine:	1997 cm^3 Petrol	1422 cm^3 Diesel
Power:	143 HP on 6000 min^{-1}	69HP on 4000 min^{-1}
Torque:	180 Nm on 2500 min^{-1}	155 Nm on 1600 - 2800 min^{-1}
Gearbox:	Manual gearbox (5 gears)	Manual gearbox (5 gears)
Drive type:	Front wheel drive (FWD)	Front wheel drive (FWD)
Maximum speed:	166 km/h	163
Acceleration 0-100 km/h:	12.7 seconds	14.8 seconds
Fuel consumption (l/100km):	10.1 (combined) 13.3 (urban) 8.2 (highway)	4.8 (combined) 6.0 (urban) 4.2 (highway)
Fuel tank capacity:	80 litres	45 litres
Car dimensions:	4.81m (length) 1.90m (width) 1.91m (height)	4.92m (length) 1.64m (width) 1.50m (height)
Gross weight:	2672 kg	1125 kg

A gas analyzer and an opacimeter must be used to measure the harmful components in the exhaust gases from the engines of the two experimental vehicles. To ensure the reliability of the measurement results obtained, it is necessary to calibrate the measuring equipment. For this purpose, before performing the measurement, the equipment has passed a control test by an accredited service for metrological measurements. A BrainBee gas analyzer and opacimeter were used in the present study. The equipment used is designed to perform measurements in stationary conditions. One of the tasks in the present study is to test the possibility of conducting measurements while driving the car in real road conditions with this type of measuring equipment. The fully equipped measuring stand is equipped with a power supply module, which provides the information for visualization of a computer with installed software for this purpose, provided by the manufacturer. Figure 2a shows the complete measuring equipment.

(a) (b) (c)

FIGURE 2. Measuring equipment (a) - Gas analyzer and smoke tester, (b) - Diagnostic tool, (c) - radio transmitter-receiver for transmitting the information for oil temperature and engine speed to the gas analyzer

The gas analyzer used is model AGS 200 [9], and the opacimeter is model OPA – 100 [10]. The measuring fields of the two measuring instruments are presented in Table 2.

TABLE 2 Measuring fields of the gas analyzer and smoke tester

Model:	BrainBee AGS 200	
Measured component	Measuring range	Resolution
CO	0 ÷ 9.99 % vol	0,01
CO_2	0 ÷ 19.9 % vol	0,1
HC hexane	0 ÷ 9,999 ppm vol	1
O_2	0 ÷ 25 % vol	0,01
NO_x	0 ÷ 5,000 ppm vol	1
Lambda	0.5 ÷ 5	0,001
Revolutions Inductance/capacitance	300 ÷ 9,990 rpm	10
Oil temperature	20 ÷ 150 °C	1
Model	BrainBee OPA-100	
Light transmission	0 ÷ 99.9 %	0,1
Light transmission	0 ÷ 9.99 M-1	0,01
Rev counter	300 ÷ 9,990 RPM heat	10
Oil Temperature	20 ÷ 150 °C	1
Smoke temp.	20 ÷ 400 °C	1

Appropriate equipment is presented in [7] to determine the engine mode in bench conditions, but in real road tests it is necessary to determine them by measuring certain indicators.

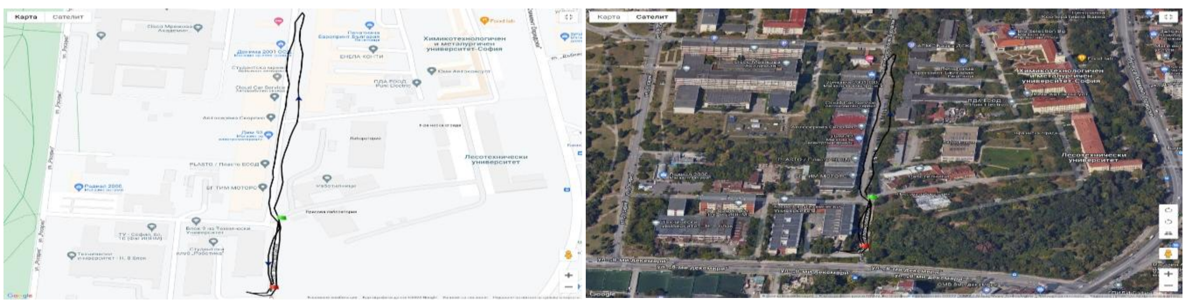
Simultaneously with the measurement of emissions from the studied vehicles, it is necessary to monitor the parameters determining the mode of operation of the engine while the vehicle is moving. For this purpose, diagnostic equipment is used, which is connected to the diagnostic connector of the car. The diagnostic equipment is Texa Navigator TXTS [11], shown in Figure 2b.

Measurements were carried out in real road conditions with vehicles in operation, observing the following methodology:

- Completion of the tested vehicle with the necessary equipment for the measurement;
- Selection of measured parameters of vehicle emissions;
- Selection of parameters determining the modes of operation of the engine;
- Determining the driving modes of the car;
- Conditions for measurements - the atmospheric and climatic conditions and the operating parameters of the vehicles must be taken into account. In order to obtain comparable results from different measurements, it is necessary to ensure identical conditions of the performed different measurements;
- Selection of the necessary software for processing and analysis of the results - When performing measurements on different cars in this way ensures the comparability of the results.

In order to achieve comparability of the measured parameters, it is necessary to ensure uniformity of the stages listed in the methodology.

The chosen route for performing all experimental measurements is identical and is presented in Figure 3a and Figure 3b. The study of the emissions from the two vehicles was conducted on April 27, 2022 in a section of the street network of the city of Sofia in the Republic of Bulgaria. The measurements were carried out consecutively with the two cars, and when examining the emissions from Citroen Jumpy to determine the emissions emitted during the operation of the car with the three different fuels, a transition was made to the selected route for each fuel once. The diesel-powered Skoda Fabia traveled the route once. In all road tests, the vehicles are driven by the same driver, which harmonizes the driving style and the mode of operation of the vehicles.



(a) (b)

FIGURE 3. Route for conducting experimental research (a) - Map view, (b) - Satellite view

According to the developed methodology, the car Citroen Jumpy is equipped with a four-component gas analyzer BrainBee AGS 200, which will measure the content of CO, CO2, NOx, HC and Labda. The location of the gas analyzer is shown in Figures 4.

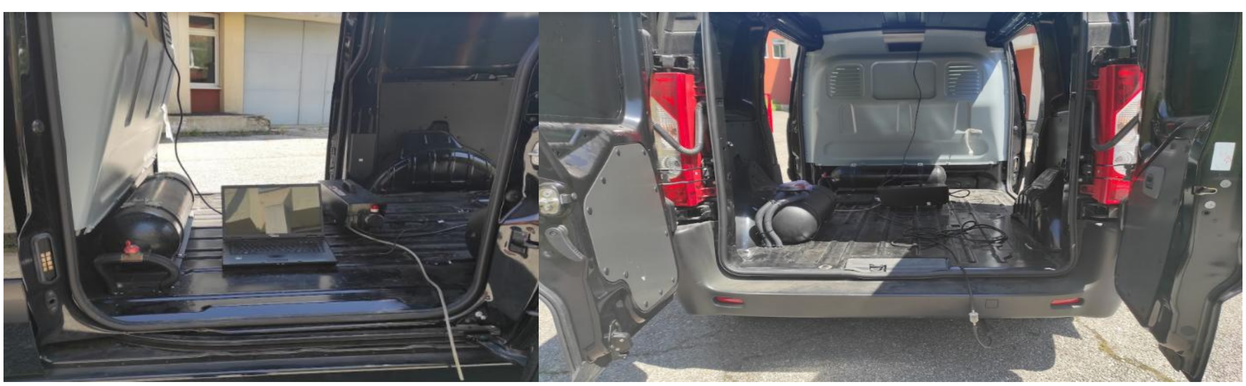
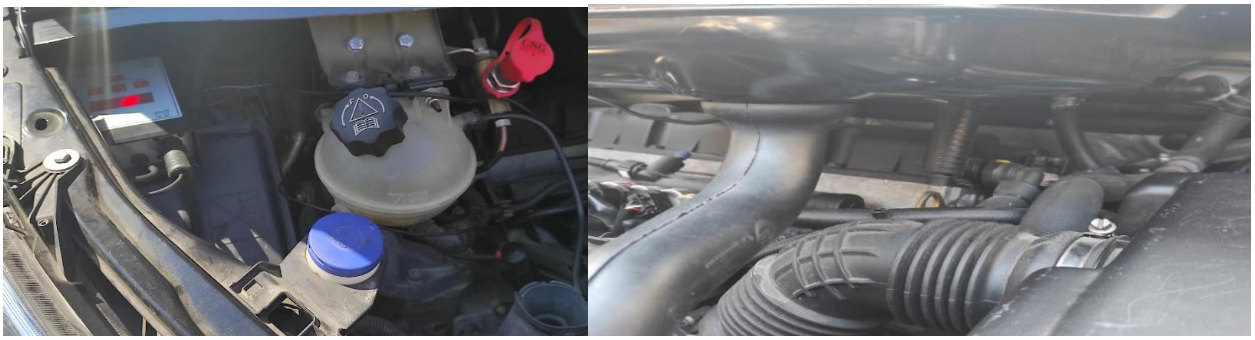


FIGURE 4. Citroen Jumpy equipped with gas analyzer BrainBee AGS 200 for measuring the emissions

To measure the engine oil temperature a thermal couple is used, which is placed in place of the engine oil level gauge (Fig. 5a). A capacitive sensor attached to the engine by a magnet is used to measure engine speed, as shown in

Figure 5b. The temperature and oil information is transmitted via the radio transmitter receiver shown in Figure 2c and Figure 5a to the gas analyzer. To monitor the operating modes of the engine, the readings of the oxygen receivers in the exhaust gases before and after the catalyst, the pressure in the filling line, the crankshaft rotation speed and the output torque, as well as the gear are selected.



(a) (b)

FIGURE 5. Sensors for engine speed and oil temperature, attached to the engine and radio transmitter-receiver for transmitting the information to the gas analyzer

Snapshots of the visualization of the readings from both instruments are presented in Figure 6a and Figure 6b.

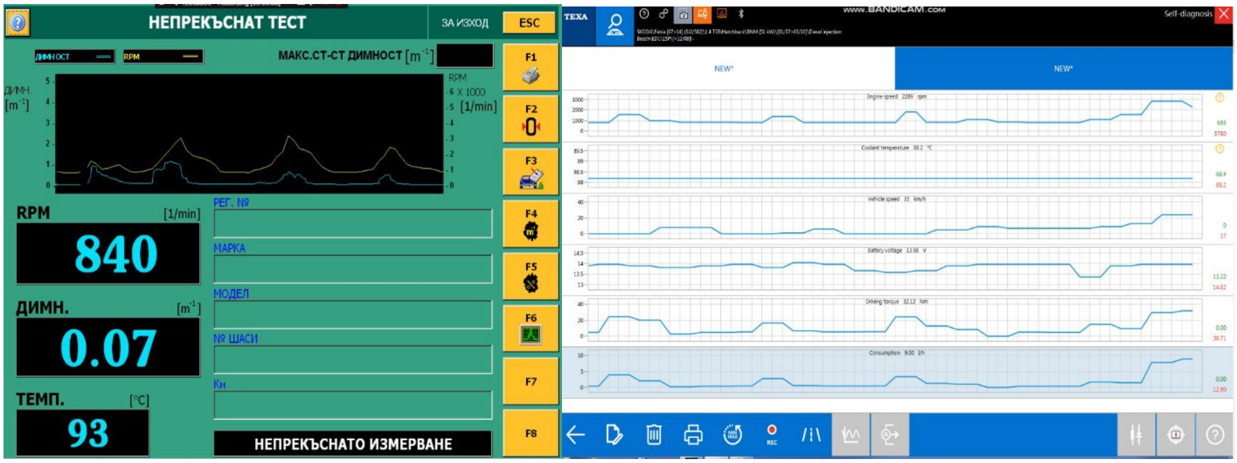
(a) (b)

FIGURE 6. Visualization of the measured values for Citroen Jumpy by the equipment (a) – From gas analyzer, (b) – From diagnostic tool

To measure emissions from the Skoda Fabia, a BrainBee OPA-100 opacimeter is used, which provides information on the percentage of smoke in the exhaust gases. The car equipped with an opacimeter is presented in the photos shown in Figure 7.

FIGURE 7. Skoda Fabia equipped with opacimeter BrainBee OPA-100 for measuring the emissions

The measurement of oil temperature and engine speed is performed in the same way as the Citroen Jumpy. Accordingly, the same measuring equipment was used for these elements mounted in the same way as described for Citroen Jumpy. In this case, the diagnostic equipment for determining the operating modes of the engine was used to measure the speed, coolant temperature and fuel consumption of the engine, as well as the battery voltage and drive torque. Snapshots of the opacimeter readings and diagnostic tool are shown in Figure 8a and Figure 8b.



(a) (b)

FIGURE 8. Visualization of the measured values for Skoda Fabia by the equipment (a) – From opacimeter, (b) – From diagnostic tool

RESULTS AND DISCUSSION

In the next part will be presented the data from the experimental measurements according to the methodology described in this part of this paper.

CONCLUSIONS

Through the developed methodology and the used measuring equipment it will be possible to determine the emissions from the vehicles in operation in real road conditions. This will provide an opportunity to compare the values measured according to the methods regulated by the legislature and the emissions actually emitted by vehicles into the environment.

This methodology is not affected by the quality of the fuel used and does not impose any requirements on it. In this way it is possible to obtain real results that take into account the type and quality of fuel used, which is especially important for determining the values of emissions from cars in operation in real road conditions.

The presented methodology takes into account the atmospheric and climatic conditions during the test, which is of particular importance for accurate and correct measurement of the actual emissions of vehicles into the environment.

The measuring equipment used by this method is relatively common, which allows for unification of measurements and their performance by the technical services that determine the technical condition of vehicles.

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